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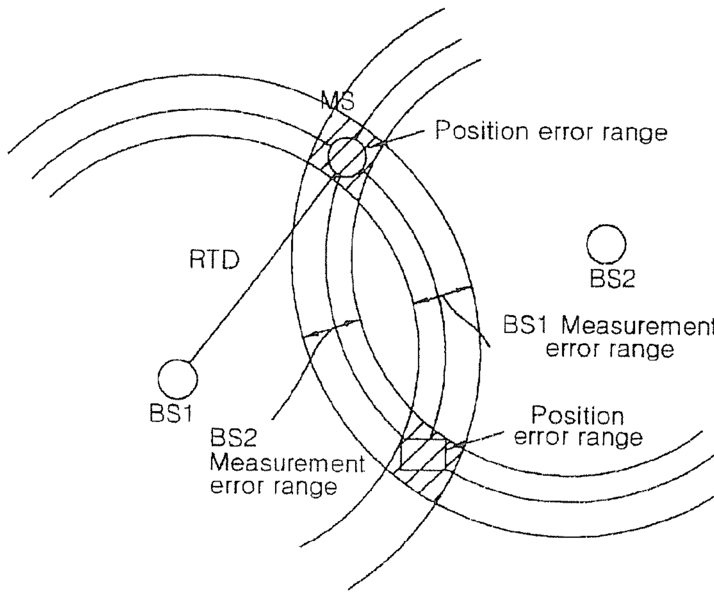

(57) Abstract: The present invention provides a method for determining a position being capable of reducing time required for acquiring measured values, and thus substantially increasing a receiving-sensitivity of GPS signal for terminals. Since navigation data is included in auxiliary information provided from a base station to a terminal, the terminal may disregard the effect of the bit phase change, therefore,the number and time for data processing can be reduced. Furthermore, since information on a cell coverage of the base station is included in the auxiliary information, the base station can reduce the code searching range in use in determining a position.

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GPS Receiver and Method for Determining Position of a Wireless Terminal

TECHNICAL FIELD

The present invention relates to a positioning system and method, and more particularly, to a Global Positioning System (GPS) receiver and a method for positioning by using GPS signals with the support of a wireless communication network.

BACKGROUND ART

Positioning systems for determining a position of a vehicle are widely used in various fields. One of the most popular positioning systems is global positioning system (GPS).

Source signals used for positioning are provided from a plurality of GPS satellites that make rounds following the circular orbits at altitudes of about 20,200 km, and GPS receivers receive GPS signals from at least 4 visible

satellites among GPS satellite constellation and calculates the position of themselves.

A GPS receiver calculates a range and a range-rate between the receiver and each satellite by calculating a time delay and a Doppler-shift of the signals from each satellite, and obtains the position and velocity of each satellite from a navigation data acquired by demodulating the signals received. Once the position and velocity information with regard to more than 4 satellites is obtained, the receiver can determine its own position and velocity.

The GPS signals are generated by a method in which a navigation data of 50 Hz spreads by using a specific pseudo random noise (PRN) code of each satellite, and, subsequently, are modulated into carrier signals of 1.5 GHz by using a binary phase shift keying (BPSK) modulation technology. Thus, to extract the navigation data from the GPS signals, the receiver should eliminate the PRN code and the carrier signal upon receiving the GPS signals.

Doppler information regarding a magnitude and a direction of the Doppler-shift is required to eliminate the carrier signals. In general, when the receiver is fixed in

position, the magnitude of the Doppler-shift caused by a satellite movement is not larger than 5kHz. Such Doppler information may be calculated by periodically searching scheme. Codes incorporated in the GPS signals comprises a coarse acquisition code (C/A code) widely known as a "civilian code", and a precise or protected code (P code) also widely known as a "military code". Each satellite has its unique code. Codes can be eliminated from the GPS signals by a method in which the GPS receiver generates the same code with the code of the corresponding satellite, and performs a convolution process simultaneously with a Doppler searching procedure.

As described above, the navigation data may be extracted after eliminating the PRN code and the carrier signals. Under the navigation data specification, a frame consists of five subframes, and a superframe consists of 25 frames. Each of Subframes 1, 2 and 3 contains information on time and position of a transmission satellite, and thus, subframe 1, 2 and 3 of each satellite have distinct information. Subframes 4 and 5 contain information common for all satellites. Therefore, subframes 4 and 5 of each satellite have the same data.

Positioning can be performed after demodulating the navigation data and obtaining positions for more than 3~4 satellites.

Meanwhile, there have been increasing needs for a wireless positioning system for determining the position of a wireless communication mobile station by using a wireless communication network. Particularly, a wireless positioning system has been most needed in the emergency rescue service field. On June 12, 1996, Federal Communication Commission (FCC) adopted a standard that all wireless communication service providers including a cellular communication system operator and a personal communication system (PCS) operator are requested to transfer a call to the Public Safety Answering Point (PSAP) without any procedure for an authentication or a credit investigation when there is an emergency rescue request call. According to the standard, the service providers are also requested to provide position information of a wireless communication mobile station with an accuracy of about 50 m for 67% of emergency rescue request calls, and about 150 m for 95% of all emergency rescue request calls. Therefore, the announcement of the standard has spurred the research for the positioning system

based on the wireless communication network.

The positioning system based on the wireless communication network may break down into three methods: a network positioning method using only communication network system; a GPS positioning method using only GPS system; and a hybrid positioning method using both the communication network system and the GPS system.

The network positioning method utilizes a geolocation method for determining the position by using a trigonometry based on a plurality of base stations. The network positioning method is divided into a remote positioning method and a self-positioning method.

In the remote positioning method, a plurality of base stations receive a signal transmitted from the mobile station, and the position is finally calculated in a central site. The remote positioning method bears an advantage that a mobile station structure needs not to be modified while it has disadvantages that the communication network system should be changed and the mobile station side cannot obtain its own position.

In the self-positioning method, mobile station performs a positioning procedure by using signals from a

plurality of the base stations. This method has advantages that it can be implemented by modifying the mobile station structure without a significant modification of the communication network system, and further the position of the mobile station is obtainable. On the contrary, the self-positioning method has disadvantages that positioning is difficult in the condition that the number of the base station with high hearibility decreases, and an error of the position may increase due to an error of non line of sight (NLOS).

Meanwhile, in the GPS positioning method, the wireless communication mobile station transmits the data measured by a GPS receiving circuit thereof to a central control center via the wireless communication network. This method has an advantage that the method can be implemented without a significant modification to the communication network system. This method, however, has disadvantages that power consumption of the mobile station and a frequency interference may increase since the mobile station involves with two systems, and positioning is not readily obtainable in indoor space where signal strength is dim. Furthermore, a time required for obtaining an initial position in the GPS

positioning system is about 1 minute, which may be allowable in an application of a general navigation system, however, may be too long in an emergency condition like the emergency rescue request.

The hybrid positioning method can cancel out the disadvantages of the network positioning method and the GPS positioning method by appropriately combining both the methods. In hybrid positioning method, the positioning is performed by the network positioning method in normal condition, but the GPS positioning method is used in the condition that the number of the neighboring base stations or the base stations with the high hearibility is insufficient. The hybrid positioning method, however, has a disadvantage that the mobile station structure becomes complex and the power consumption increases.

Recently, in order to overcome the problems of the prior arts, a network-assisted GPS positioning method has been developed in which roles of the base station and the mobile station are divided in processing the data in obtaining the position on the basis of the GPS signals. In accordance with the network-assisted GPS positioning method, the base station transmits an auxiliary data required for

improving the GPS positioning speed to the mobile station via the wireless communication network, and the mobile station calculates a pseudo-range per each satellite by using the auxiliary data. The auxiliary data may include the satellite position data at measurement time and the Doppler information of the satellite and the like. The mobile station may transmit the positioning data to a central control center after directly positioning based on the pseudo-ranges for the satellites. As an alternative, the mobile station help the base station, a mobile switching center and the central control center to perform the positioning by providing the pseudo-ranges for the base station. The network-assisted GPS positioning method has advantages that it is possible to reduce the positioning time, to perform the positioning inside a room with weak signal intensity, and to improve the positioning accuracy compared to the prior network positioning systems.

Technologies for the network assisted GPS positioning method may be divided into three fields : the first technology for reducing the time required for a signal acquisition and the positioning procedure in the GPS receiver embedded in the mobile station by providing an

appropriate auxiliary data from the base station to the mobile station via the wireless communication network; second technology for improving a receiving sensitivity of the GPS signals for performing the positioning indoor; and third technology for reducing the power consumption of the system.

The satellite position and Doppler information are required for reduction of a signal acquisition time, i.e., the time to first fix (TTFF). The satellite position may be calculated on the basis of a satellite ephemeris data and a GPS time data, and the Doppler information may be calculated from a clock drift of the a receiver local oscillator and a velocity of the satellite and the mobile station. Therefore, the base station provides the auxiliary data including a time information, a frequency information and the Doppler information for the mobile station in the network-assisted GPS positioning method.

In the network-assisted GPS positioning method, the time information is a fundamental data for synchronizing the mobile station and the base station with a reference time called as universal time coordinate. A mobile station modem provides the time information synchronized with the base

station for the GPS receiver so that the GPS receiver can obtain the satellite position and reduce a search range for calculating a code offset. When the base station provides accurate carrier frequency information for the mobile station, it is possible to correct the clock drift of the GPS receiver local oscillator. The method for providing the accurate carrier frequency information is disclosed in U.S. patent No. 5,663,734 granted to the Precision Tracking Incorporated. Furthermore, the method for providing the Doppler information for visible satellites is proposed by the U.S. patent 5,781,156 granted to the Snaptrack, Inc. and U.S. patent 5,663,734 as above.

Meanwhile, the receiving sensitivity of the GPS signals should be improved to successively perform the positioning for indoor application. In order to improve the receiving sensitivity, in addition to providing the auxiliary information from the base station to the mobile station as described, there has been proposed a method in which the mobile station performs a plurality of convolution operations or fast Fourier transform (FFT) operations in tracking and demodulating the GPS signals. For example, in U.S. patents Nos. 5,663,734 and 5,781,156 and another U.S.

patent No. 5,884,214 of the Snaptrack Inc., it is disclosed a procedure for tracking and demodulating signals by performing a plurality of the convolution operations and the FFT operations. Another conventional method for improving the receiving sensitivity is an extension of the signal integration time as disclosed in U.S. patent No. 5,884,214. However, it is impossible to perform the signal integration for more than 20 miliseconds in case that the data is unknown since the GPS signals comprise 50Hz data. Furthermore, if there is an error in the Doppler information estimated, the limitation for the signal integration time becomes worse. Two methods may be used to overcome the limitation for the signal integration time. The first method is a correction of the clock drift of the receiver by using the accurate carrier signal of the base station. In addition, in accordance with the second method, the signals are integrated after being divided into several short time periods and magnitude alone is integrated again hereinafter, or the signals may be searched by estimating a Doppler error in order to prevent a signal attenuation caused by a Doppler error.

Furthermore, in order to reduce the power consumption

of the mobile station with the network-assisted GPS positioning function, for example, U.S. patents Nos. 5,663,734 and 5,781,156 disclose a circuit capable of selectively supplying the power to a radio-frequency signal input side and a snapshot memory only while receiving the GPS signals, supplying the power to a digital signal processor (DSP) while processing intermediate frequency (IF) data, but not supplying the power to these devices during another procedure or while the positioning is not required.

DISCLOSURE OF INVENTION

An object of the present invention is to provide a positioning method capable of reducing the signal acquisition time (i.e., time to first fix) and improving the receiving sensitivity of the GPS signals of the mobile station.

According to an aspect of the present invention, the base station provides the mobile station with an auxiliary data including a pseudo-range and a time information for the corresponding base station, and a navigation data via a

wireless communication network. The mobile station does not have to consider a bit phase shift by the navigation data in obtaining a C/A code from the GPS signals. In addition, the mobile station can extend the signal integration time to at least 20 miliseconds. Therefore, the time required for processing the signals can be reduced since the number of the data process times decreases for the data of a predetermined amount.

In addition, in accordance with the present invention, the auxiliary data includes information on a cell coverage of the base station communicated with the mobile station, and may further include a round trip delay (RTD) information between the base station and the mobile station, and/or a sector information and a relaying equipment (hereinafter "repeater") information. The base station can reduce the signal acquisition time by reducing a calculation amount and a code search range during positioning procedure on the basis of the auxiliary data, and can improve the receiving sensitivity.

BRIEF DESCRIPTION OF DRAWINGS

The above and other objects and features of the present invention will become apparent from the following description of a preferred embodiment given in conjunction with the accompanying drawings, in which:

Fig. 1 shows a preferable embodiment of the GPS mobile station according to the present invention;

Fig. 2 is a flow chart illustrating a self-positioning procedure in the GPS mobile station of Fig. 1;

Fig. 3 is a flow chart illustrating a remote positioning procedure in the GPS mobile station of Fig. 1;

Fig. 4 shows a signal process procedure by an intermediate frequency (IF) sampling of Fig. 2 in more detail;

Fig. 5 is a waveform diagram illustrating a structure of general GPS signals;

Fig. 6 is a waveform diagram illustrating a procedure to eliminate a carrier and a navigation data from the GPS signals;

Fig. 7 conceptually illustrates a coherent integration procedure for a received C/A code;

Fig. 8 is a conceptual diagram illustrating a procedure to reduce a code search range on the basis of an

estimation of a limitation value of a time delay;

Fig. 9 is a draw for explaining a procedure to interpolate correlation values for points between sampling time in order to determine the point with the highest correlation value;

Fig.10 is a diagram for explaining a positioning auxiliary data from the base station and the usage of the auxiliary data in accordance with the present invention;

Fig.11 is a diagram for explaining a method for calculating a search range used for a calculation of a pseudo-range between a satellite and the mobile station;

Fig.12 illustrates a searching method in the case that information on the pesudo-range is provided by the base station;

Fig. 13 shows an example of a RTD statistical value collected by the base station;

Fig.14 illustrates the search range for acquiring the second satellite signal in the positioning method using the pseudo-range pre-calculated for the other satellite;

Fig.15 illustrates the search range for acquiring the third satellite signal in the positioning method using the pseudo-range pre-calculated for the other satellite;

Fig. 16 shows the search range in the embodiment using sector information;

Fig.17 illustrates a condition enabling for the mobile station to receive signals from two base stations; and

Fig. 18 shows a range of a position error in the case that at least two base stations are used.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, a preferred embodiment of the present invention will be described in detail with reference to the accompanying drawings.

Fig. 1 shows a preferable embodiment of the GPS mobile station according to the present invention.

The GPS mobile station 10 of Fig. 1 includes a modem 12 for transmitting/receiving a wireless signals, an antenna 14 used for transmitting/receiving the wireless signals, and a GPS receiving unit 20. The GPS mobile station can transmit signals to a wireless communication base station (hereinafter, "the base station") and receive signals from the base station through a wireless communication link, and can receive the GPS signals from a GPS satellite.

In the preferable embodiment of the present invention, the base station 2 is a part of a code division multiple access (CDMA) communication network, which provides a communication service to the mobile station in the corresponding cell coverage. In particular, a base station transceiver subsystem (BTS) of the base station used in the present invention includes a GPS receiver, and generates, stores and periodically updates positioning auxiliary information for providing to the mobile station 10 during continuously processing a navigation data. When the base station transmits a start request command of the positioning to the mobile station 10 or receives a positioning start request from the mobile station 10, the base station 2 provides the positioning auxiliary information for the mobile station 10 so that enables the mobile station 10 to perform a rapid and ease positioning by means of the auxiliary information. The positioning auxiliary information will be described in more detail below.

Referring to Fig. 1, the modem 12 modulates uplink communication signals into a CDMA signals and transmits modulated signals to the base station 2, and demodulates the CDMA signals transmitted from the base station. The modem 12

and the GPS receiving unit 20 are connected by means of a serial I/O interface port. If the GPS receiving unit 20 receives a positioning command from the base station, or if the positioning command is applied to the GPS receiving unit 20 by a user or an operation of a program embedded in the mobile station, the GPS receiving unit 20 receives the positioning auxiliary information through the modem 12 and receives the GPS signals from the GPS satellites, and determines the position of the mobile station by using the positioning auxiliary information and the GPS signals received.

According to the preferred embodiment of the present invention, the mobile station 10 is designed to include the modem 12 and the GPS receiving unit 20 in one housing of a monolithic construction. However, in accordance with another embodiment of the present invention, the GPS receiving unit 20 is separately prepared and connected to the modem 12 in the mobile station by means of a serial interface port of the mobile station. The mobile station may be, for example, a cellular mobile phone, a personal digital assistant (PDA) and the like.

In the embodiment as depicted in Fig. 1, the GPS

receiving unit 20 comprises a microprocessor 22, a power controller 24, a frequency synthesizer 26, an antenna 28, a down converter 30, a analog/digital converter (hereinafter "A/D converter") 32, a snapshot memory and a digital signal processor 36.

The microprocessor 22 performs data communication with the modem 12, and also performs a power control operation. That is, the microprocessor 22 controls the power controller 24 not to supply or supply minimum stand-by power to the down converter 30, the A/D converter 32, the snapshot memory 34 and the digital signal processor 36, and to supply full power to these parts during a few steps of the whole positioning procedure.

Therefore, the down converter 30, the A/D converter 32, the snapshot memory 34 and the digital signal processor 36 are maintained in a low-power stand-by mode while the positioning is out of operation. If the positioning procedure starts, at first, full power is supplied to the down converter 30, the A/D converter32 and the snapshot memory 34.

The down converter 30 acquires the GPS signals with RF bandwidth received at the antenna 28, and converts frequency

bandwidth of the GPS signals into the intermediate frequency bandwidth by using a local oscillation signal from the frequency synthesizer 26.

The A/D converter 32 performs a sampling and a quantizing for intermediate frequency signals (hereinafter "IF signals") from the down converter 30 by using a sampling clock received from the frequency synthesizer 26. The A/D converter 32 stores resultant digital data (hereinafter "IF sampling signals") in the snapshot memory 34. The digital signal processor 36 is supplied with only the standby power while the procedure from the sampling of the GPS signals to a storing of the IF sampling signals is performed.

Meanwhile, the down converter 30 and the A/D converter 32 enter into the low-power standby mode after the IF sampling signals are stored in the snapshot memory, and full power is supplied for the snapshot memory 34 and the digital signal processor 36. The digital signal processor 36 calculates the pseudo-range for each satellite by using the IF sampling signals stored in the snapshot memory 34 and the auxiliary information received from the base station through the microprocessor 22. Appropriate algorithms are programmed in the digital signal processor 36 .

The digital signal processor provides pseudo-range information for the microprocessor 22 after calculating the pseudo-range for each satellite. The microprocessor 22 controls the power controller 24 again to convert the snapshot memory 34 and the digital signal processor 36 to the low-power standby mode after receiving the pseudo-range information. Subsequently, the microprocessor 22 processes the pseudo-range information based on an operation mode. That is, in a self-positioning mode, the mobile station determines its own position, the microprocessor 22 calculates the position of the mobile station by using the pseudo-range information, and displays the resultant position data for the mobile station on a screen or transmits the resulting data to the base station 2. In a remote positioning mode, a separate central control center determines the position of the mobile station, the microprocessor 22 transmits the pseudo-range information to the central control center via the base station 2, and allows the central control center to determine the final position of the mobile station.

Structure of the GPS mobile station shown in Fig. 1 is similar to the structure disclosed in U.S.P.N. 5,663,734 and

5,781,156. The GPS mobile station according to the present invention, however, differs from those disclosed in the patents in that the type of the positioning auxiliary information received from the base station 2 is different. The positioning auxiliary information in accordance with the present invention, in particular, further comprises a navigation data acquired by the base station, a range of a cell coverage for the base station, i.e., an effective range of the base station, and/or a data on the round trip delay (RTD) between the base station and the mobile station. Accordingly, the positioning procedure in accordance with the present invention presents distinction from the methods as proposed in the above U.S. patents.

Fig. 2 is a flow chart illustrating a positioning procedure using the GPS mobile station of Fig. 1.

At first, a communication link should be established between the base station 2 and the modem 12 in the mobile station 10 (Step 100). The mobile station 10 corrects a time error by using the signals transmitted from the base station 2 pursuant to a pre-determined protocol. In this condition, the frequency synthesizer 26 of the GPS receiving unit 20 minimizes a clock drift error and a Doppler shift by sharing

a clock with the modem 12 of the mobile station.

Meanwhile, the base station 2, if necessary, can transmit a positioning start command to the mobile station 10 in the state that the communication link is established (Step 102). The positioning start command has a specific time mode in which the positioning is performed at a specific time, and an immediate mode for immediately performing the positioning procedure. The mobile station 10 transmits an acknowledge signal to the base station in response to the receiving of the positioning start command. If the specific time is specified in the positioning start command, the mobile station 10 transmits a positioning start notification signal to the base station at the specific time.

As an alternative, the mobile station 10 may transmit a request to start the positioning procedure to the base station, and the base station 2 transmits the positioning start notification signal to the mobile station 10 after receiving the request.

Subsequently, the mobile station 10 receives the GPS signals, and stores the IF sampling signal in the snapshot memory 34 (Step 104). At the same time, the base station 2 provides the positioning auxiliary information for the

mobile station 10 (Step 106). The positioning auxiliary information prepared at the base station 2 is transmitted to the modem 12 of the mobile station 10 and then transferred to the microprocessor 22 of the GPS receiving unit 20 by means of a serial communication (Step 108).

In accordance with the preferred embodiment, the auxiliary information for use in positioning in the GPS receiving unit 20 of the mobile station 10 includes a first part provided by the base station 2 and a second part pre-calculated and stored. The variety of the auxiliary information is disclosed in table 1.

TABLE 1

Type of the auxiliary information		Usage
Items provided from the base station	Satellite code (SV_ID)	Selecting satellite transmitting GPS signal to be processed
	Pseudo-range between base station and satellite (ρ_{BS})	Initial value of mobile station pseudo-range for corresponding satellite
	Satellite orbit (Ephemeris)	Calculating Doppler shift for corresponding satellite
	Navigation data	Eliminating navigation data from signals received at mobile station
	Time information	Setting time for calculating satellite position
		Setting positioning time
		Setting reference time for calculating mobile station pseudo-range
	Effective range of base station (R_{BS})	Calculating code search range
	Round trip delay (RTD) time	Reducing code search range
		Correcting time error due to distance between base station and mobile station
Items already known	Clock error of mobile station	Calculating code search range
	Clock error of base station	Calculating code search range

Meanwhile, an effective range ($R_{Repeater}$) of a repeater may be provided in place of or along with a cell coverage, i.e., an effective range of the base station for reducing the code search range. Furthermore, sector information can be included in the positioning auxiliary information. The positioning auxiliary information may further include a

position of the base station (or repeater) communicating with the mobile station, information on whether communication device is the base station or the repeater. In particular, the effective range (R) of the base station in case that information on the repeater is unknown or the repeater is not used may differ from the effective range (R_{BS}) of the base station in case that the base station is used.

The GPS receiving unit 20 processes the IF sampling signals and calculates pseudo-ranges for all or part of visible satellites after collecting the IF sampling signal at step 106 and step 108 and receiving the positioning auxiliary information from the base station 2 (Step 110). Upon calculating of the pseudo-range, the microprocessor 22 calculates the position of the mobile station based on the pseudo-ranges for visible satellites and ephemeris data of the satellite, and transmits data on the position of the mobile station to the base station 2 (Steps 112 and 114).

Referring to Fig. 3 explaining the remote positioning, the calculated pseudo-range information is transferred to the central control center via the base station 2 so that the central control center can calculate the position of the

mobile station.

Fig. 4 shows a signal processing by an intermediate frequency (IF) sampling of Fig. 2, i.e., step 110 in more detail. Referring to Fig.4, at first, a C/A code for a visible satellite is generated (Step 150). Generally, the C/A code is a pseudo noise (PN) code having 1 MHz frequency periodically repeating every 1milisecond, i.e., every 1,023 bits. In step 150, the C/A code is generated at a PN code generator in the digital signal processor 36. As an alternative, the C/A code may be obtained from a look-up table loaded at a memory. After the C/A code is generated, the C/A code included in the received GPS signals (hereinafter "the received C/A code") is recovered and coherent-integrated by means of the IF sampling signal stored in the snapshot memory 34 (Step 154). Furthermore, the pseudo-range is determined by synchronizing timing between a generated C/A code and an integrated C/A code referring to a time tag in the navigation data bit received at the base station 2, and subsequently calculating a code delay time between two codes (Steps from 156 to 168).

Steps from 156 to 168 will now be described in more detail.

In general, the GPS signals consist of the navigation data, the C/A code and the carrier. A phase of the carrier is inverted when the navigation or the C/A code shifts a logic state. Meanwhile, the carrier is first eliminated from the GPS signals since the pseudo-range is calculated by means of a delay time of the C/A code included in the GPS signals. Generally, a change of bit phase due to the navigation data should be considered for eliminating the carrier. That is, in case that the navigation data of 50Hz frequency remains, it is impossible to extend an integration time to more than 20ms in the coherent-integration procedure, and thus there is a limitation in improving the receiving sensitivity by means of the integration.

In the GPS mobile station shown in Fig. 1, however, the carrier and the navigation data can be eliminated from the GPS signals, more particularly, from the IF sampling signal since the digital signal processor 36 receives the navigation data from the base station 2 by way of the modem 12 and the microprocessor 22 as shown in Fig. 6. Referring to Fig. 6, after the navigation data are eliminated, all the C/A codes have identical phase. Therefore, the change of bit phase due to the navigation data is no longer a concern, and

thus, data processing time for a specific data can be reduced since the integration time can be extended to more than 20ms. For example, the data processing time in case with the 100ms integration time can be reduced to 1/10 of the case with the 10ms integration time, since if a data for 1 second should be processed, 10 blocks and 100 blocks are generated in the former case and the latter case respectively. The Doppler shift should be eliminated from the GPS signals along with the carrier. The method for eliminating the Doppler shift is widely known to those who skilled in the art, and thus detailed description therefore will be omitted

The code delay time can be calculated by confirming a correlation with a C/A code generated by the convolution operation since only the received C/A code remains after eliminating the navigation data and the carrier from the GPS signals. Particularly, the correlation between the generated C/A code and a received C/A code coherent-integrated is used in order to improve the receiving sensitivity.

Fig. 7 illustrates a coherent integration procedure for the received C/A code. Referring to Fig. 7, the received

C/A code is divided by one period unit and summed in a preferred embodiment of the present invention. If the GPS signals of 1 second are stored in the snapshot memory, 1000 periods of the C/A code can be added during the coherent integration, and thus the C/A code may have 1000 times larger amplitude compared to that of prior to the integration (Step 154). The receiving sensitivity can substantially be improved since the convolution operation is performed on the basis of higher-intensity signals. In Fig. 5, Fig.6 and Fig. 7, a pulse presents one period of the C/A code.

Referring back to Fg.4, in step 156, the GPS receiving unit of the mobile station calculates a timing and determines the search range in order to acquire the correlation value by means of the integrated C/A code and the received C/A code. In addition, the GPS receiving unit finds a peak correlation value while searching the C/A code in the search range by the convolution operation, and coherent-integrates the correlation value (Step 158 and 160). The procedure from step 152 to step 160 is repeatedly performed until the searching process for whole search range ends (Step 162).

The search for the whole search range of the C/A code is needed according to a prior art using a conventional convolution operation. In accordance with the present invention, however, a time delay search range can be significantly reduced by using the pseudo-range (or along with the RTD information or the sector information) from the base station, and thus calculation time for a time delay can be reduced. For example, if a marginal value of the time delay can be estimated by means of the positioning auxiliary information as shown in Fig. 8, it is sufficient to perform the code search within the marginal value since real value of the time delay may be within the marginal value. The marginal value of the time delay for use in reducing the search range can be estimated on the basis of the RTD information, the sector information for the corresponding cell, the pseudo-range to the base station and the like. The method for estimating the marginal value may be described below in more detail.

The GPS receiving unit determines the pseudo-range after searching for whole search range. A resolution power of the calculated time delay value may be determined according to the sampling frequency, and thus a positioning

error may increase in case of low sampling frequency. In order to overcome this problem, the GPS receiving unit in accordance with the present invention determines the point with highest correlation value by interpolating the correlation value between sampling points, and determines a corresponding pseudo-range value (Step 164 and 166). The procedure according to the steps from 150 to 166 is sequentially applied to each of the visible satellites (Step 168).

<u>Navigation data generation and transmission in the base station</u>

Time synchronization is necessarily required in order for the base station 2 to provide the navigation data and for the mobile station 10 to use the navigation as the positioning auxiliary data. That is, signal loss may occur if synchronization is not achieved in applying the navigation data transmitted from the base station 2 to the IF signal collected in the mobile station 10. Therefore, it is required to synchronize the time the mobile station 10 collects the IF signal with the time the base station 2 acquires the navigation data. In the present invention, the

base station 2 attaches a time-tag at the acquired navigation data and transmits it to the mobile station 10, and the mobile station 10 synchronizes collection time of the IF signal based on the time-tag.

In general, a phase difference exists in the navigation data received from each satellite even though the navigation data are received at the same time since the distances between the GPS receiver and each satellite vary. Thus, the mobile station 10 first calculates a bit phase at a collection start time of the navigation data before using the navigation data. The base station 2 has the pseudo-range for each satellite and the collection time of the navigation data, and the pseudo-range corresponds to the time difference between a signal transmission and receiving times. Thus, the signal transmission time of a satellite can be expressed as Equation 1.

[Equation 1]

$$T_{trans}^{SVi} = T_{received} - \frac{\rho_{BS}^{SVi}}{C},$$

wherein, T_{trans}^{SVi} is the signal transmission time of the i-th satellite, $T_{received}$ is the signal receiving time and $\frac{\rho_{BS}^{SVi}}{C}$ is the pseudo-range between the base station and the i-th

satellite.

The bit phase can be obtained from the signal transmission time since the signals transmitted form the satellite is synchronized with a GPS reference time. The bit phase can finally expressed as Equation 2.

[Equation 2]

$$BP_{SVi} = fr\{T_{trans}^{SVi} / 20m\sec\} = BP_{SVi}^{true} + \sigma_{BSclock},$$

wherein, $\sigma_{BSclock}$ is an error occurred by the time difference between the base station clock and the GPS reference time.

The bit phase as Equation 2 is calculated on the basis of the base station 2, and thus, the bit phase at the mobile station side may contain a time synchronization error occurred from a distance difference. Therefore, the time synchronization error will be corrected by means of the RTD information in the present invention, and the resulting bit phase information used in the mobile station can be expressed as Equation 3.

[Equation 3]

$$BP_{MS} = BP_{BS} - RTD + \sigma_{BSclock} + \sigma_{MSclock} = BP_{BS} - RTD + \sigma_{clock},$$

wherein, σ_{clock} presents a clock error of the mobile station (MS) and the base station (BS).

Reduction of the code search range by means of the RTD

A tracking and acquisition of the carrier and the code for the satellite signal should be first performed to calculate the distance between the satellite and the mobile station for use in determining the mobile station's position. The code from the GPS signal may be acquired by executing the convolution operation for the received signal from the satellite and the generated signal in the mobile station during a code period. If no additional information is provided by the base station, the whole range of the signals for 1 ms, i.e., the C/A code period of the GPA signals should be searched. Thus, provided that a code period comprises of m number of samples, $2m^2$ times of addition and multiplication operation are required for calculating the correlation value. According to the present invention, however, the time required for the code search can be substantially reduced by also providing an auxiliary information including the RTD information for the mobile station.

Fig.10 is a diagram for explaining a positioning auxiliary data from the base station and the use of the

auxiliary data in accordance with the present invention. In Fig. 10, the symbol "SV1~SV3" denotes the satellites, "BS" means the base station, "Repeater1~Repeater3" means the repeaters, and "MS1~MS4" means the mobile station, respectively. In addition, the symbols "ρ_{BS}", "ρ_{MS}", "R_{BS}", "$R_{Repeater}$", "R", and "R_{RTD}" represent a pseudo-range between a satellite and the base station, a pseudo-range between the satellite and the mobile station, an effective range of the base station, an effective range of the repeater, an effective range of the base station in case that repeater information is unknown, and a distance corresponding to the RTD information respectively.

Use of the pseudo-range ρ_{BS} calculated on the basis of the base station

Provided that the pseudo-range calculated at the base station is provided for the mobile station, it is unnecessary to search the whole search range of the C/A code one period. That is, the mobile station should search only a part of the C/A code based on ρ_{BS} instead of the whole search range since the mobile station is located near to the corresponding base station, and thus there is little

difference between ρ_{BS} and ρ_{MS}. The search range is determined on the basis of a distance difference and a time synchronization difference between the mobile station and the base station.

Fig.11 is a diagram for explaining a method for calculating a search range used for a calculation of ρ_{MS}. The symbol of θ_{BS} in Fig. 11 represents an elevation angle of the satellite relative to the base station. Maximum error of the pseudo-range due to the distance difference between the base station and mobile station is expressed by $R_{BS}\cos(\theta_{MS})$ obtained by performing the orthogonal projection of the effective range R_{BS} of the base station to the vector directed from the base station to the satellite. A search reference point, i.e., a phase of the C/A code, will be expressed as Equation 4.

[Equation 4]

$$T_{\rho_{BS}} = fr\{\rho_{BS}/(\lambda_{CA} \cdot C)\},$$

wherein, "fr{}" is a function calculating a value below decimal point, "λ_{CA}" represents a wavelength of the C/A code and "C" is the speed of light. The search range can be calculated on the basis of the time synchronization error between two systems and $R_{BS}\cos(\theta_{MS})$, and the C/A code phase

$T_{\rho_{MS}}$ at the mobile station 10 will be expressed as Equation 5.

[Equation 5]

$$T_{\rho_{BS}} - R_{BS}\cos(\theta_{BS}) - \sigma_{clock} \le T_{\rho_{MS}} \le T_{\rho_{BS}} + R_{BS}\cos(\theta_{BS}) + \sigma_{clock},$$

wherein, σ_{clock} represents the time synchronization error occurring between two systems.

Fig.12 illustrates a searching method in the case information on the pseudo-range is provided by the base station. Referring to Fig. 12, the code search is performed by executing the convolution operation for the generated C/A code and the received C/A code integrated within the search range defined as Equation 5.

Provided that a repeater is installed inside the cell coverage of the base station and the mobile station can not confirm which repeater communicates with itself, it is preferred to use "R" shown in Fig.10 as the effective range of the base station instead of "R_{BS}". The search range may be extended since the value of "R" is larger than "R_{BS}".

<u>Use of the distance information corresponding to the RTD</u>

The RTD is information on a distance between the base

station and the mobile station, and thus the base station may already have or easily obtain the RTD. If the mobile station is provided with the RTD information or the distance information corresponding to the RTD from the base station, the mobile station can further reduce the search range. That is, the mobile station sufficiently searches within R_{RTD} instead of the entire effective range of the base station, and thus the search range will be expressed as Equation 6.

[Equation 6]

$$T_{\rho_{BS}} - R_{RTD}\cos(\theta_{BS}) - \sigma_{clock} \le T_{\rho_{MS}} \le T_{\rho_{BS}} + R_{RTD}\cos(\theta_{BS}) + \sigma_{clock} .$$

Signals passing through the repeater may have larger RTD value than signals not-passing through the same. Meanwhile, if a plurality of repeaters is installed inside the cell coverage, it can be known which repeater passes through a communication link by means of a RTD statistical value.

Fig. 13 shows an example of a RTD statistical value collected at the base station. For the signals passing through the repeater, the search reference point $T_{\rho_{MS}}$ should be calculated by means of the pseudo-range $\rho_{\mathrm{Re}\,peater}$ and the elevation angle $\theta_{\mathrm{Re}\,peater}$ based on the position of the repeater,

and the effective range $R_{\mathrm{Re}\,peater}$ of the repeater. The search reference point and the search range of signals passing through the repeater are expressed as Equation 7 and Equation 8 respectively.

[Equation 7]

$$T_{\rho_{\mathrm{Re}\,peater}} = fr\{\rho_{\mathrm{Re}\,peater} / (\lambda_{CA} \cdot C)\}\,,$$

[Equation 8]

$$T_{\rho_{\mathrm{Re}\,peater}} - R_{\mathrm{Re}\,peater}\cos(\theta_{\mathrm{Re}\,peater}) - \sigma_{clock} \le T_{\rho_{MS}} \le T_{\rho_{\mathrm{Re}\,peater}} + R_{\mathrm{Re}\,peater}\cos(\theta_{\mathrm{Re}\,peater}) + \sigma_{clock}$$

, wherein, the effective range $R_{\mathrm{Re}\,peater}$ of the repeater can be approximately rewritten as Equation 9 by using the RTD information and a time delay $D_{\mathrm{Re}\,peater}$ of optical cable between the base station and the repeater.

[Equation 9]

$$R_{\mathrm{Re}\,peater} = R_{RTD} - D_{REpeater}$$

Use the pre-calculated pseudo-range for another satellite

When the mobile station calculates the pseudo-range for another satellite after calculating the pseudo-range for the first satellite, the search range can be further reduced in satellite signal acquisition procedure by using the pre-

calculated pseudo-range for the first satellite. In accordance with this embodiment, after obtaining the pseudo range for the first satellite, the mobile station determines whether the mobile station is located in nearer side to the satellite than the base station by comparing the base station pseudo-range ρ_{BM} and the mobile station pseudo-range ρ_{MS} , and can limit the search range based on the determination result.

Fig.14 illustrates the search range for acquiring the second satellite signal in the positioning method using the pre-calculated pseudo-range for another satellite. Referring to Fig. 14, the first satellite SV1 and the second satellite SV2 are projected in a 2-dimensional plane centering on the base station. The symbols in Fig. 14, Pi , ψi , ρ_{BS}^{SVj} , P_{SVj} , ψ_{BS}^{SVj} and θ_{BS}^{SVj} represent a i-th position, an azimuth of the i-th position, a pseudo-range between the base station and a j-th satellite, a projection position of the j-th satellite, an azimuth of the j-th satellite and an elevation angle of the j-th satellite, respectively.

If ρ_{BS}^{SV1} is smaller than ρ_{BS}^{SV2} in Fig. 14, the mobile station will be located in a semi-circle region (the shaded region) adjacent to the first satellite SV1 of the effective

range of the base station, and thus, it is sufficient to search the shaded semi-circle region for acquiring signals from the second satellite SV2. Though the search range may vary depending on the position of the second satellite, the maximum and minimum value of the pseudo-range in the semi-circle region may be obtained respectively. The maximum and minimum value of the pseudo-range will be one of four points including two cross points (P_3, P_4) at a circle intersect a line dividing the circle into two semi-circles, the intersection point P_2 of the circle and a straight line directing to the line-of-sight of the second satellite SV2, and a center point P_1, i.e., a position of the base station, respectively. Therefore, the maximum and minimum value of the pseudo-range can be determined by calculating distances from the second satellite SV2 to four points $P_1 \sim P_4$, and comparing the calculated distances. The distance from the satellite to each satellite can be expressed by Equation 10.

[Equation 10]

$$\begin{aligned} r_{P_i}^{SV_2} &= | P_i - P_{SV_2} | \\ &= \{ (R_{BS} \cos(\psi_i) - \rho_{BS}^{SV_2} \cos(\theta_{BS}^{SV_2}) \cos(\psi_{BS}^{SV_2}))^2 \\ &\quad + (R_{BS} \sin(\psi_i) - \rho_{BS}^{SV_2} \cos(\theta_{BS}^{SV_2}) \sin(\psi_{BS}^{SV_2}))^2 \}^{1/2} \end{aligned} .$$

The search range will be determined by the maximum value $MAX(r_{\Pi}^{SV_2})$ and the minimum value $MIN(r_{\Pi}^{SV_2})$, and further be

expressed by Equation 11.

[Equation 11]

$$T_{\rho_{BS}}^{SV_2} + \{MIN(r_{P_1}^{SV_2}) - \rho_{BS}^{SV_2}\} - \sigma_{clock} \le T_{\rho_{MS}}^{SV_2} \le T_{\rho_{BS}}^{SV_2} + \{MAX(r_{P_1}^{SV_2}) - \rho_{BS}^{SV_2}\} + \sigma_{clock}.$$

In case the pseudo-range of the second satellite is calculated, the mobile station can further reduce the search range for acquiring the third satellite signals.

The search range for acquiring the third satellite signals is shown in Fig. 15. As similar to the method according to Fig. 14, maximum and minimum value of the search range for the third satellite can be determined by calculating and comparing distances from the third satellite to four points $P_1 \sim P_4$. If fourth satellite's signals need to be acquired subsequently, the required search range can be further reduced in a similar manner. Therefore, calculation volume can be reduced and the possibility for miscalculating the C/A code phase due to noise can be accordingly reduced.

Use of the sector information

The sector information may be used as one of the positioning auxiliary data. In general, three sectors exist for one base station. In accordance with the present invention, the search range can further be reduced by means

of the sector information. A method for reducing the search range by using the sector information can be implemented in a similar manner as the method using the pre-calculated pseudo-range. The search range according to this embodiment is illustrated in Fig. 16.

In case of using the sector information, the mobile station can reduce the search range from the searching procedure for the first satellite signals. In Fig. 16, a region the solution of the mobile station position can exist is defined to an inside region of a gray fan-shaped sector. The maximum and minimum value of the pseudo-range will be one of four points including two cross points (P_3, P_4) at circle intersects a line dividing the sector, the intersection point P_2 of the circle and a straight line directing to the line-of-sight of a satellite, and a center point P_1, i.e., a position of the base station, respectively. Therefore, the maximum and minimum value of the pseudo-range can be determined by calculating distances from the second satellite to four points, and comparing the calculated distances. Furthermore, from the second satellite, the necessary signals can be more effectively acquired by considering the pre-calculated pseudo-range for the other

satellite and searching the cross region.

Reduction of the search range for the correlation value by means of more than two base station

The description mentioned above is for reducing the search range by means of the RTD in case the mobile station communicates with one base station. However, the search range may extend as the RTD value increases. In case the mobile station 10 is located far away from the communicating base station, the mobile station may be adjacent to the other base station, and thus a communication possibility with the other station may increases. Therefore, the additional measurements for the corresponding satellite can be used in reducing the search range. That is, in case the mobile station receives signals from at least two base stations shown as Fig. 17, the mobile station can further reduce the C/A code search range. The position information obtained according to this procedure, however, may include an error due to a non line-of-sight propagation and multi path effect and the like, and thus the other solution as presented the quadrangle region in Fig. 17 is additionally

provided.

Use of two base stations

Given that the mobile station MS communicates with the first base station BS1, and the RTD between the first base station BS1 and the mobile station MS is already known, the distance r_1 between the first base station BS1 and the mobile station MS and the distance r_2 between the second base station BS2 and the mobile station MS will be expressed by Equation 12 respectively.

[Equation 12]

$$r_1 = RTD \times C$$
$$r_2 = r_1 + C \cdot \tau + C(t_{PNoffset1} - t_{PNoffset2})$$

wherein, "C" is the speed of light, "$t_{PNoffseti}$" is a PN code offset specifically allocated to each base station and "τ" is a correlation delay time of the first base station BS1 and the second base station BS2.

If the position of the mobile station, the positions of the first base station and the second base station are represented as (x, y, z), (x_1, y_1, z_1) and (x_2, y_2, z_2) respectively, a measurement Equation for the distance will be expressed by Equation 13.

[Equation 13]

$$\rho_1 = \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2} + \omega_1$$
$$\rho_2 = \sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2} + \omega_2,$$

wherein, the ω_1 is a first measurement error comprising a measurement error ω_{m1} and a NLOS error b_{NLOS1}, and ω_2 is a total error including the first measurement error $\omega_{m1} + b_{NLOS1}$ and a second measurement error $\omega_{m2} + b_{NLOS2}$. A 3-dimentional position cannot be obtained since the number of the measurement equation is only two. However, if an altitude of the mobile station is known, Equation 14 can be used.

[Equation 14]

$$x^2 + y^2 + z^2 = R_E^2 = (R_E^{true})^2 + \Delta b,$$

wherein, Δb means a square of altitude error. Equation 14 includes an error of Δb because of the assumption that the altitude is already known. Equation 13 can be rewritten as Equation 15.

[Equation 15]

$$\begin{aligned}(\rho_1 - \omega_1)^2 &= (x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 \\ &= R_E^2 + R_{E1}^2 - 2(x_1 x + y_1 y + z_1 z) \\ (\rho_2 - \omega_2)^2 &= (x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2 \\ &= R_E^2 + R_{E2}^2 - 2(x_2 x + y_2 y + z_2 z)\end{aligned}$$

wherein, " R_{Ei}^2 " represents a distance from earth's

center to the i-th base station BSi, which includes no error factor since exact positions for all base stations are known.

Equation 15 can be rewritten as Equation 16 by arranging x and y terms with respect to z.

[Equation 16]

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{1}{2(x_1y_1 - x_2y_1)} \begin{bmatrix} y_2 & -y_1 \\ -x_2 & x_1 \end{bmatrix} \begin{bmatrix} R_E^2 + R_{E1}^2 - (\rho_1 - \omega_1)^2 - 2z_1z \\ R_E^2 + R_{E2}^2 - (\rho_2 - \omega_2)^2 - 2z_2z \end{bmatrix}$$
$$= \frac{1}{2(x_1y_1 - x_2y_1)} \begin{bmatrix} (y_2 - y_1)(R_E^2 + R_{E1}^2) - y_2(\rho_1 - \omega_1)^2 + y_1(\rho_2 - \omega_2)^2 + 2z(y_1z \\ (x_1 - x_2)(R_E^2 + R_{E1}^2) + x_2(\rho_1 - \omega_1)^2 + x_1(\rho_2 - \omega_2)^2 + 2z(x_2z_1 \end{bmatrix}$$

Equation 16 may be simply rewritten as Equation 18 by using coefficients defined as Equation 17.

[Equation 17]

$$a_x = \frac{(y_2 - y_1)(R_E^2 + R_{E1}^2) - y_2(\rho_1 - \omega_1)^2 + y_1(\rho_2 - \omega_2)^2}{2(x_1y_1 - x_2y_1)}$$
$$a_y = \frac{(x_1 - x_2)(R_E^2 + R_{E1}^2) + x_2(\rho_1 - \omega_1)^2 + x_1(\rho_2 - \omega_2)^2}{2(x_1y_1 - x_2y_1)}$$
$$a_{z1} = \frac{(y_1z_2 - y_2z_1)}{(x_1y_2 - x_2y_1)}$$
$$a_{z2} = \frac{(x_2z_1 - x_1z_2)}{(x_1y_2 - x_2y_1)}$$

[Equation 18]

$$x = a_x + a_{z1}z$$
$$y = a_y + a_{z2}z\,',$$

wherein, a_x and a_y include the measurement error and the an altitude error. Equation 18 can be rewritten as

Equation 19 in consideration of these error factors.

[Equation 19]

$$a_x = a_x^{true} + \Delta a_x$$
$$= a_x^{true} + \frac{2(y_2\rho_1\omega_1 - y_1\rho_2\omega_2) + y_2\omega_1{}^2 - y_1\omega_2{}^2 + \Delta b(y_2 - y_1)}{2(x_1y_1 - x_2y_1)}$$
$$a_y = a_y^{true} + \Delta a_y$$
$$= a_y^{true} + \frac{2(x_2\rho_1\omega_1 - x_1\rho_2\omega_2) + x_2\omega_1{}^2 - x_1\omega_2{}^2 + \Delta b(x_1 - x_2)}{2(x_1y_1 - x_2y_1)}$$

A term "z" can be expressed by Equation 20 by substituting Equation 18 for Equation 14.

[Equation 20]

$$z = \frac{(a_x a_{z1} + a_y a_{z2}) \pm \sqrt{(a_{z1}^2 + a_{z2}^2 + 1)R_E^2 - (a_x a_{z2} - a_y a_{z1})^2 - (a_x^2 + a_y^2)}}{(a_{z1}^2 + a_{z2}^2 + 1)}$$

Two solutions for the position of the mobile station can be obtained by substituting "z" term of Equation 20 for Equation 18.

Use of at least three base stations

In case of using more than or equal to three base stations, the measurement equation for the distance will be expressed by Equation 21.

[Equation 21]

$$\rho_i = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} + \omega_i, \qquad i=1,2,3,\ldots, n,$$

wherein, a subscript notation is an identifier for the

base station. Equation 21 can be rewritten as Equation 22.

[Equation 22]

$$-2x_i x - 2y_i y - 2z_i z = \rho_i^2 - R_{Ei}^2 - R_E^2 .$$

Equation 22 will be rewritten as Equation 23 by applying to n numbers of satellites.

[Equation 23]

$$HX = R_a + R_E^2 R_b ,$$

wherein, symbol "X" means a position to be determined, and "H", "R_a" and "R_b" are expressed by Equation 24.

[Equation 24]

$$H = \begin{bmatrix} -2x_1 & -2y_1 & -2z_1 \\ -2x_2 & -2y_2 & -2z_2 \\ \mathrm{M} & \mathrm{M} & \mathrm{M} \\ -2x_n & -2y_n & -2z_n \end{bmatrix},$$

$$R_a = \begin{bmatrix} \rho_1^2 - R_{E1}^2 \\ \rho_2^2 - R_{E2}^2 \\ \mathrm{M} \\ \rho_n^2 - R_{En}^2 \end{bmatrix}, \qquad R_b = \begin{bmatrix} -1 \\ -1 \\ \mathrm{M} \\ -1 \end{bmatrix}, \qquad X = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The position "X" can be finally determined by using Equation 25.

[Equation 25]

$$X = (H^T H)^{-1} H^T R_a + R_E^2 (H^T H)^{-1} H^T R_b .$$

The solution cannot be directly obtained from Equation 23 due to the known "R_E^2". A quadratic equation, however,

can be derived from Equation 14. And thus, two of the navigation solutions can be determined by calculating two of R_E^2 by means of the quadratic equation and substituting it for Equation 25.

Therefore, the position of the mobile station can be determined in case of using more than or equal to two base stations, and an error range of the position may be determined in accordance with the measurement error after determining two of the navigation solution. However, the code search range can be further reduced by using at least two base stations since only gray region shown in Fig. 18 should be searched.

In accordance with the present invention, the volume of calculation in positioning procedure can be reduced and the receiving sensitivity can be improved since the auxiliary information provided from the base station to the mobile station includes the navigation data. Therefore, the positioning procedure can be performed even inside a door with low-intensity GPS signals. Furthermore, the code search range can also be reduced by means of the auxiliary information further including the cell coverage information of the base station. The GPS receiver and the positioning

method in accordance with the present invention can be widely applied not only to an emergency rescue service but also to an intelligent transportation system, a criminal tracking service, a cellular system design, a location-based billing and the like.

While the embodiments illustrated in the figures and described above are presently preferred, it should be understood that these embodiments are offered by way of example only. The invention is not limited to a particular embodiment, but extends to various modifications, combinations, and permutations that nevertheless fall within the scope and spirit of the appended claims.

WHAT IS CLAIMED IS:

1. A positioning method using a receiver for use in a satellite positioning system for receiving auxiliary information through a wireless communication network with at least one base station and measuring a pseudo-range for each of a plurality of satellites by means of the auxiliary information, comprising the steps of :

(a) receiving GPS signals including a carrier, a navigation data and a first pseudo noise code from each of a plurality of the satellites, and generating an intermediate frequency (IF) sampling signal by converting the GPS signals into an IF bandwidth signals and sampling the IF bandwidth signals;

(b) receiving the auxiliary information including a time-tagged navigation data from the base station, and generating a second pseudo noise code corresponding to the first pseudo noise code;

(c) recovering the first pseudo noise code by eliminating the navigation data by means of the time-tagged navigation data from the IF sampling signals; and

(d) determining the pseudo-range by calculating a

delay time of the first noise code on the basis of a correlation value of the first pseudo noise code and the second pseudo noise code.

2. The method as claimed in claim 1, wherein step (d) including the steps of:

(d1) performing a coherent integration for the first pseudo noise code; and

(d2) calculating the delay time by performing a non-coherent integration for the second pseudo noise code and the integrated first pseudo noise code during a time interval longer than 20 miliseconds.

3. The method as claimed in claim 1 or claim 2, wherein the time-tagged navigation data in step (b) includes the navigation data received by the base station and a signal receiving time at the base station, and step (c) including the steps of:

(c1) calculating a signal transmission time of the satellite by the equation as follow; and

(c2) eliminating the navigation data based on the signal transmission time,

$T_{trans}^{SVi} = T_{received} - \frac{\rho_{BS}^{SVi}}{C}$, wherein, T_{trans}^{SVi} is the signal transmission time of i-th satellite, $T_{received}$ is the signal receiving time at the base station and ρ_{BS}^{SVi}/C is the pseudo-range between the i-th satellite and the base station.

4. The method as claimed in claim 3, wherein step (c1) has the steps of:

(c11) calculating a bit phase for the base station by means of the following equation (1),

$$BP_{SVi} = fr\{T_{trans}^{SVi} / 20m\sec\} = BP_{SVi}^{true} + \sigma_{BSclock} \ldots\ldots (1),$$

wherein, $\sigma_{BSclock}$ is an error occurred from the time difference between the base station clock and the GPS reference time and fr{} is a function calculating a value below decimal point; and

(c12) calculating a bit phase for the mobile station by means of equation (2),

$$BP_{MS} = BP_{BS} - RTD + \sigma_{BSclock} + \sigma_{MSclock} = BP_{BS} - RTD + \sigma_{clock} \ldots\ldots..(2),$$

wherein, σ_{clock} presents a clock error of the mobile station (MS) and the base station (BS).

5. A positioning method using a receiver for use in a satellite positioning system for receiving auxiliary

information through a wireless communication network with at least one signal transmission/receiving system and measuring a pseudo-range for each of a plurality of the satellites by means of the auxiliary information, comprising the steps of :

(a) receiving GPS signals including a carrier, a navigation data and a first pseudo noise code from each of a plurality of the satellites, generating an intermediate frequency (IF) sampling signal by converting the GPS signals into IF bandwidth signals and sampling the IF bandwidth signal, recovering the first pseudo noise from the IF sampling signals, and generating a second pseudo noise code corresponding to the first pseudo noise code;

(b) receiving pseudo-range information for the signal transmission/receiving system, effective range information representing a distance range between the signal transmission/receiving system and the receiver; and

(c) determining the pseudo-range by calculating a delay time of the first pseudo noise code on the basis of a correlation value of the first pseudo noise code and the second pseudo noise code,

wherein, in the procedure (c), the receiver reduces a

search range for use in calculating the correlation value by means of a pseudo-range information for the signal transmission/receiving system and the effective range information and performs a correlation value calculation only for the reduced search range.

6. The method as claimed in claim 5, wherein step (c) includes the steps of:

(c1) establishing a searching reference point by means of the pseudo-range for the signal transmission/receiving system; and

(c2) determining the search range around the searching reference point by using the effective range information.

7. The method as claimed in claim 6, wherein the signal transmission/receiving system is a base station in the wireless communication network;

the searching reference point in the procedure (c1) is calculated by equation (3) based on a pseudo-range ρ_{BS} for the base station,

$$T_{\rho_{BS}} = fr\{\rho_{BS}/(\lambda_{CA} \cdot C)\} \ldots\ldots\ldots\ldots (3),$$

wherein, fr{} is a function calculating a value below

decimal point, λ_{CA} is a wavelength of the C/A code and C is the speed of light; and

the search range for C/A code phase $T_{\rho_{MS}}$ in the procedure (c2) is determined by equation (4),

$$T_{\rho_{BS}} - R_{BS}\cos(\theta_{BS}) - \sigma_{clock} \le T_{\rho_{MS}} \le T_{\rho_{BS}} + R_{BS}\cos(\theta_{BS}) + \sigma_{clock} \ldots\ldots\ldots (4),$$

wherein, σ_{clock} is a time synchronization error occurring between the base station and the receiver.

8. The method as claimed in claim 6, wherein the signal transmission/receiving system is a base station in the wireless communication network;

the searching reference point in the procedure (c1) is calculated by equation (5) based on a pseudo-range ρ_{BS} for the base station,

$$T_{\rho_{BS}} = fr\{\rho_{BS}/(\lambda_{CA}\cdot C)\} \ldots\ldots\ldots\ldots (5),$$

wherein, fr{} is a function calculating a value below decimal point, λ_{CA} is a wavelength of the C/A code and C is the speed of light; and

the search range for C/A code phase $T_{\rho_{MS}}$ in the procedure (c2) is determined by equation (6),

$$T_{\rho_{BS}} - R_{RTD}\cos(\theta_{BS}) - \sigma_{clock} \le T_{\rho_{MS}} \le T_{\rho_{BS}} + R_{RTD}\cos(\theta_{BS}) + \sigma_{clock} \ldots\ldots\ldots (6),$$

wherein, RTD represents a round trip delay (RTD)

information between the base station and the receiver and σ_{clock} is a time synchronization error occurring between the base station and the receiver.

9. The method as claimed in claim 6, wherein the signal transmission/receiving system is a repeater with respect to a base station in the wireless communication network;

the searching reference point in the procedure (c1) is calculated by equation (7) based on a pseudo-range $\rho_{\mathrm{Re}\,peater}$ for the repeater,

$$T_{\rho_{\mathrm{Re}\,peater}} = fr\{\rho_{\mathrm{Re}\,peater}/(\lambda_{CA}\cdot C)\} \text{............}\ (7),$$

wherein, fr{} is a function calculating a value below decimal point, λ_{CA} is a wavelength of the C/A code and C is the speed of light; and

the search range for C/A code phase $T_{\rho_{MS}}$ in the procedure (c2) is determined by equation (8),

$$\begin{aligned} &T_{\rho_{\mathrm{Re}\,peater}} - R_{\mathrm{Re}\,peater}\cos(\theta_{\mathrm{Re}\,peater}) - \sigma_{clock} \le T_{\rho_{MS}} \\ &\le T_{\rho_{\mathrm{Re}\,peater}} + R_{\mathrm{Re}\,peater}\cos(\theta_{\mathrm{Re}\,peater}) + \sigma_{clock} \end{aligned} \text{............}\ (8),$$

wherein, $R_{\mathrm{Re}\,peater}$ is an effective range of the repeater, $\theta_{\mathrm{Re}\,peater}$ is an elevation angle of the satellite at the repeater and σ_{clock} is a time synchronization error occurring between the base station and the receiver.

10. A receiver for use in a satellite positioning system for receiving auxiliary information through a wireless communication network with at least one signal transmission/receiving system and measuring a pseudo-range for each of a plurality of the satellites by means of the auxiliary information, comprising :

a down converter for receiving GPS signals in radio frequency bandwidth and down-converting the frequency bandwidth of the GPS signals to an intermediate frequency bandwidth by using local oscillation signals;

an analog/digital converter for sampling intermediate frequency (IF) signals from the down converter by means of designated sampling clocks and outputting IF sampling signals;

a snapshot memory for storing the IF sampling signals;

a digital signal processor for recovering a first pseudo noise code in the IF sampling signals by eliminating a navigation data included in the IF sampling signals by means of a time-tagged navigation data, for generating a second pseudo noise code corresponding to the first pseudo noise code, and for calculating the pseudo-range for each of

a plurality of the satellites by calculating a delay time of the first pseudo noise code on the basis of a correlation value of the first pseudo noise code and the second pseudo noise code;

a power controller for controlling a power supply to the down converter, the analog/digital converter, the snapshot memory and the digital signal processor; and

a control means for receiving the time-tagged navigation data through a modem, for providing the time-tagged navigation data for the digital signal processor, and for controlling the power controller.

11. The receiver as claimed in claim 10, wherein the receiver further comprises a frequency synthesizer for generating the local oscillation signals and the sampling clocks by means of predetermined reference clock, wherein the frequency synthesizer shares the reference clock with the control means.

12. A receiver for use in a satellite positioning system for receiving auxiliary information through a wireless communication network with at least one signal

transmission/receiving system and measuring a pseudo-range for each of a plurality of the satellites by means of the auxiliary information, comprising :

a down converter for receiving GPS signals in radio frequency bandwidth and down-converting the frequency bandwidth of the GPS signals to an intermediate frequency bandwidth by using local oscillation signals;

an analog/digital converter for sampling intermediate frequency (IF) signals from the down converter by means of designated sampling clocks and outputting IF sampling signals;

a snapshot memory for storing the IF sampling signals;

a digital signal processor for recovering a first pseudo noise code in the IF sampling signals, for generating a second pseudo noise code corresponding to the first pseudo noise code, and for calculating the pseudo-range for each of a plurality of the satellites by calculating a delay time of the first pseudo noise code on the basis of a correlation value of the first pseudo noise code and the second pseudo noise code;

a power controller for controlling a power supply to the down converter, the analog/digital converter, the

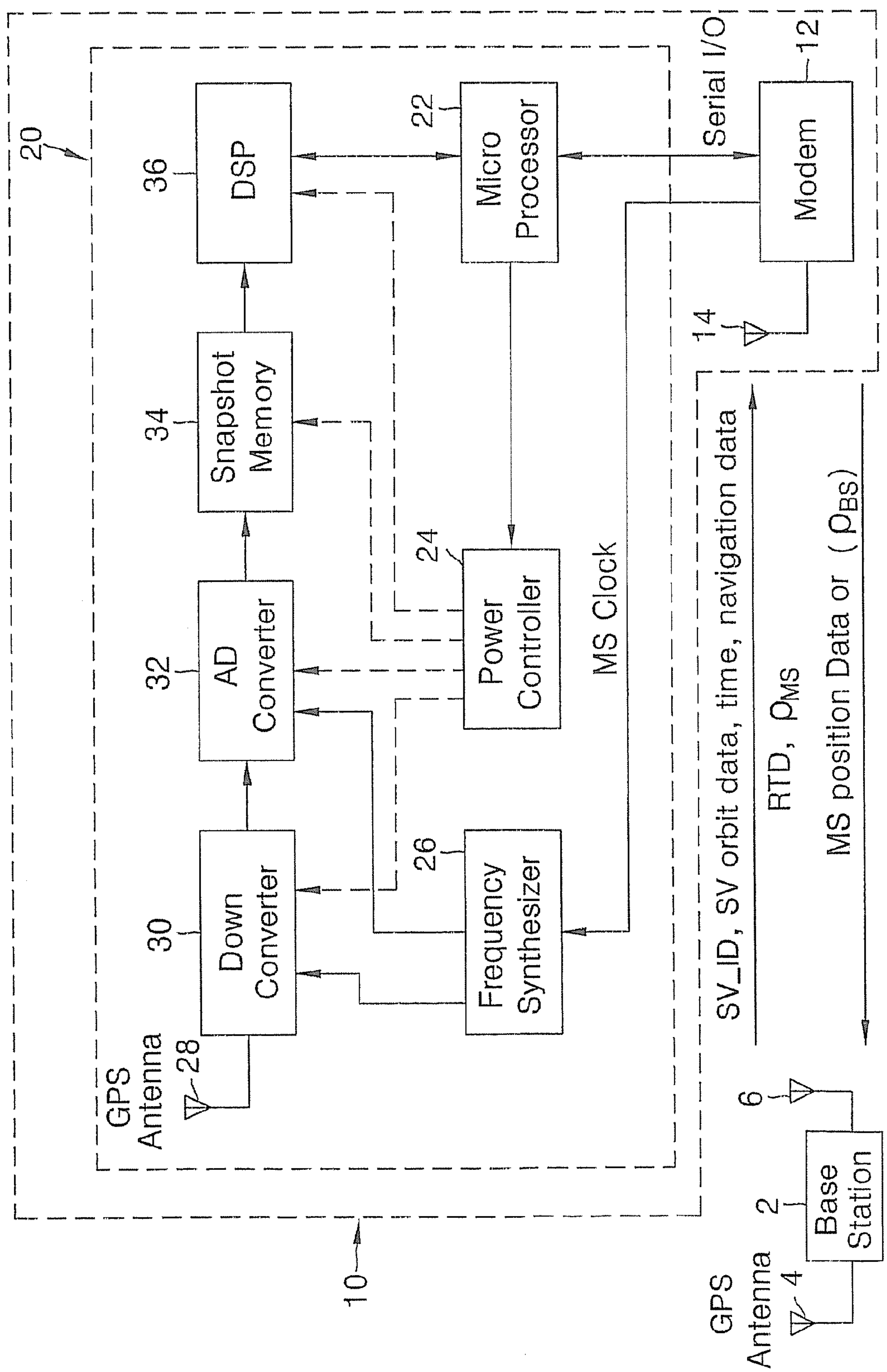
snapshot memory and the digital signal processor; and

a control means for receiving pseudo-range information for the signal transmission/receiving system and time-tagged effective range information representing a distance range between the signal transmission/receiving system and the receiver from the signal transmission/receiving system by way of a modem, for providing the pseudo-rnage information and the time-tagged effective range information for the digital signal processor, and for controlling the power controller,

wherein, the digital signal processor reduces a search range for use in calculating the correlation value by means of the pseudo-range for the signal transmission/receiving system and the effective range information, and performs the correlation value calculation only for the reduced search range.

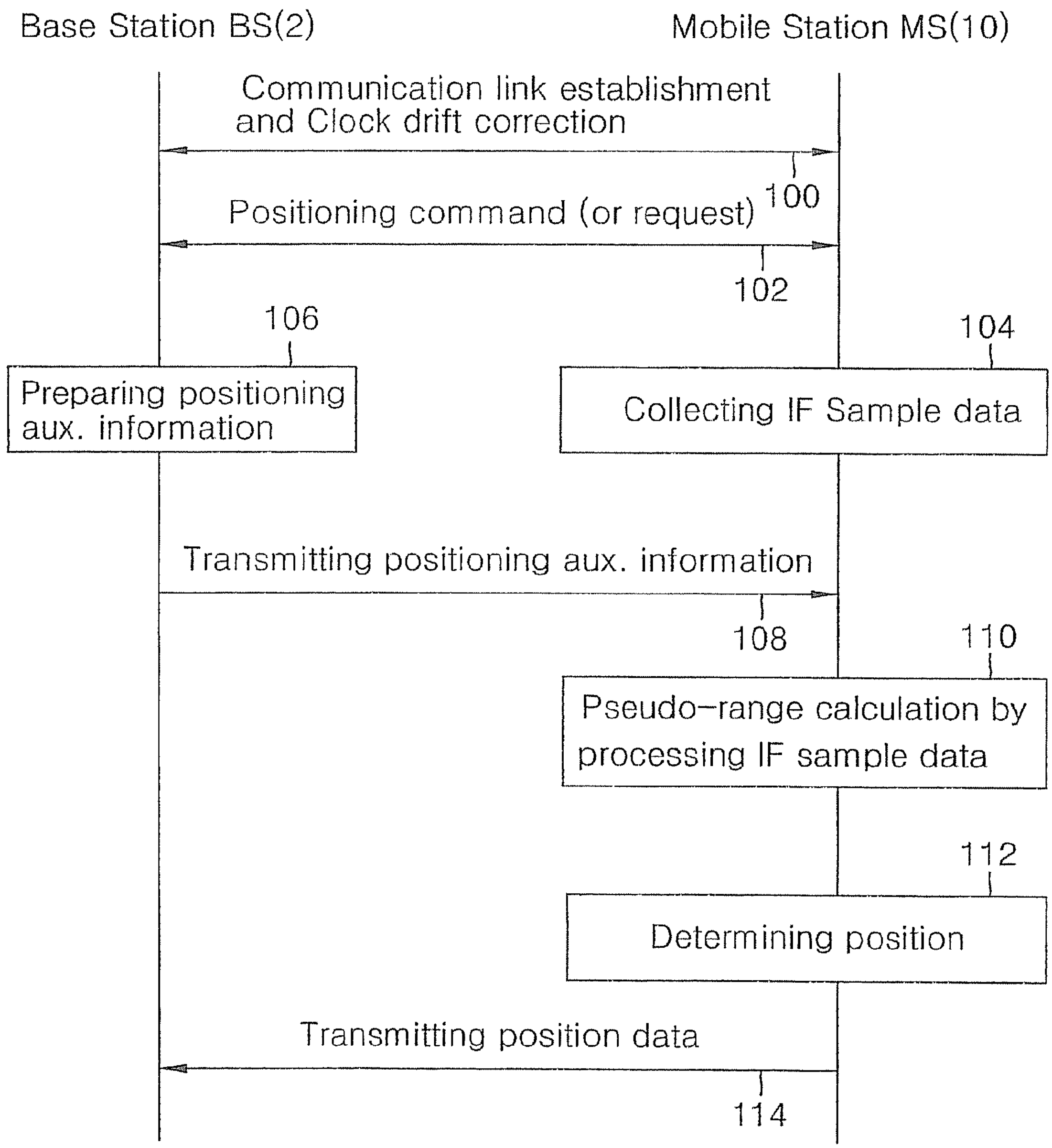
13. The receiver as claimed in claim 12, wherein the receiver further comprises a frequency synthesizer for generating the local oscillation signals and the sampling clocks by means of predetermined reference clock, wherein, the frequency synthesizer shares the reference clock with

the control means.



10
20
GPS Antenna
28
Down Converter
30
AD Converter
32
Snapshot Memory
34
DSP
36
Frequency Synthesizer
26
Power Controller
24
Micro Processor
22
MS Clock
Serial I/O
Modem
12
14
SV_ID, SV orbit data, time, navigation data
RTD, ρ_{MS}
MS position Data or (ρ_{BS})
6
Base Station
2
GPS Antenna
4

FIG. 1



Base Station BS(2)
Mobile Station MS(10)
Communication link establishment and Clock drift correction
100
Positioning command (or request)
102
106
Preparing positioning aux. information
104
Collecting IF Sample data
Transmitting positioning aux. information
108
110
Pseudo-range calculation by processing IF sample data
112
Determining position
Transmitting position data
114

FIG.2

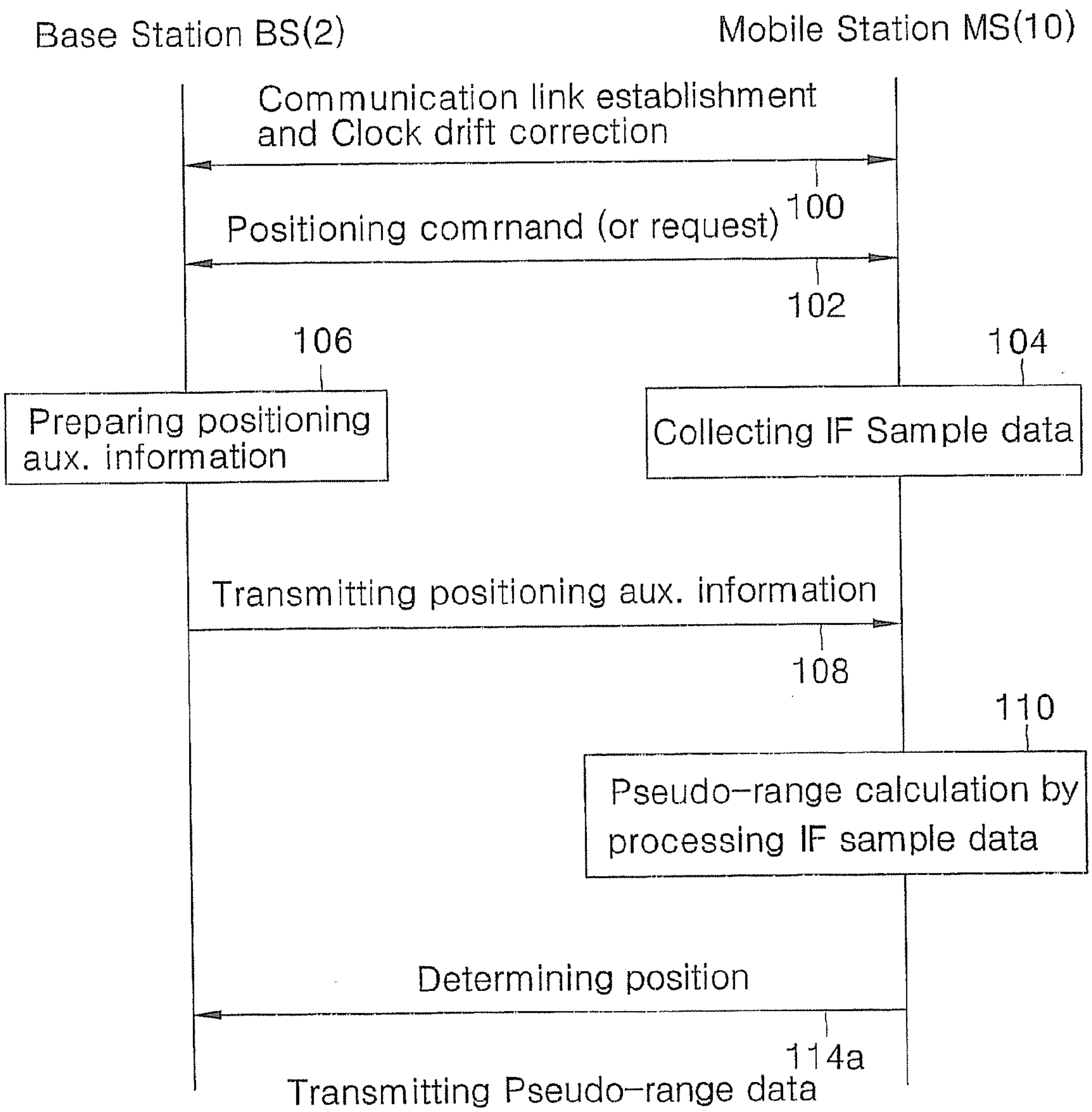

Base Station BS(2)
Mobile Station MS(10)
Communication link establishment and Clock drift correction
100
Positioning comrnand (or request)
102
106
104
Preparing positioning aux. information
Collecting IF Sample data
Transmitting positioning aux. information
108
110
Pseudo-range calculation by processing IF sample data
Determining position
114a
Transmitting Pseudo-range data

FIG.3

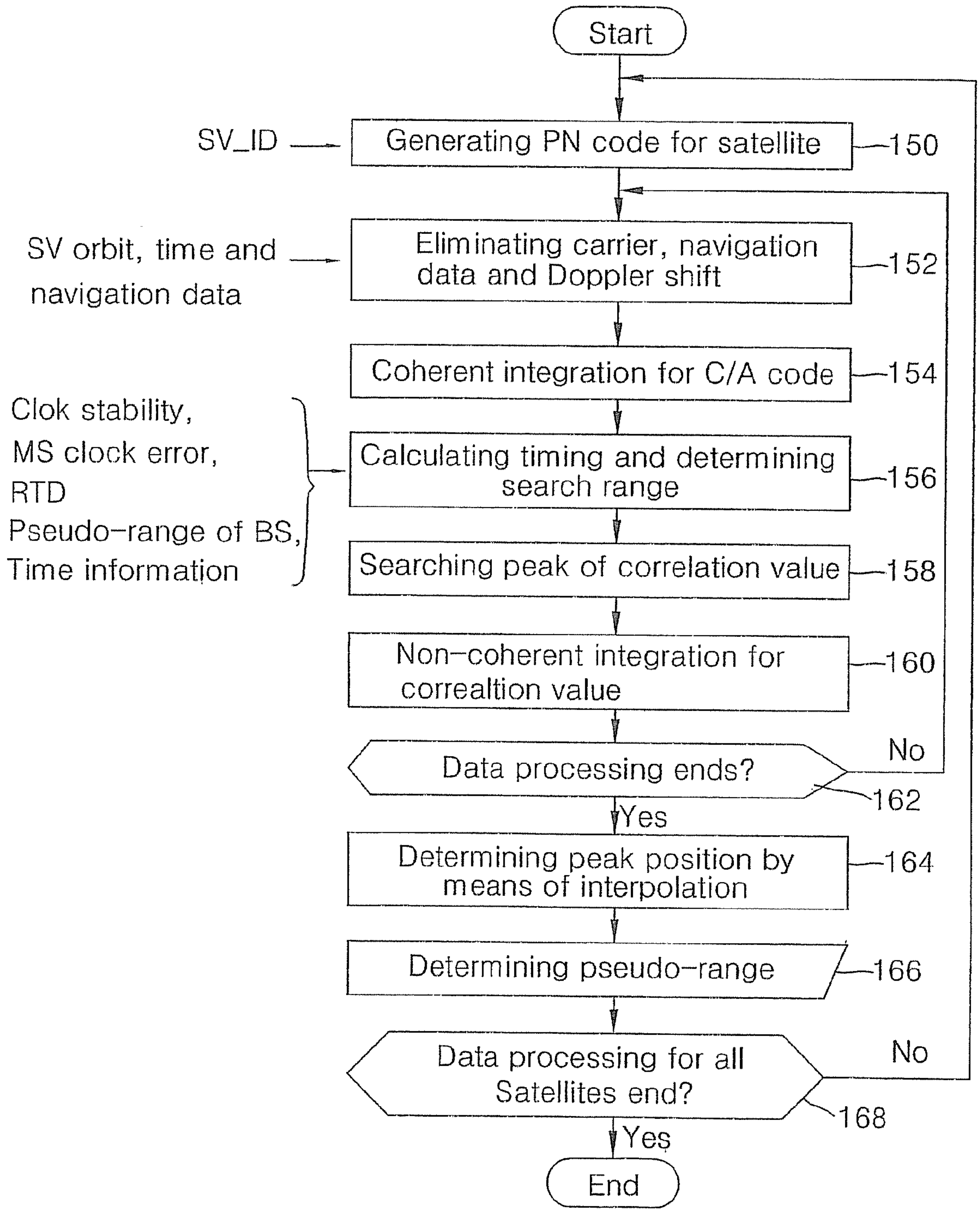

Start
SV_ID
Generating PN code for satellite
150
SV orbit, time and navigation data
Eliminating carrier, navigation data and Doppler shift
152
Coherent integration for C/A code
154
Clok stability,
MS clock error,
RTD
Pseudo-range of BS,
Time information
Calculating timing and determining search range
156
Searching peak of correlation value
158
Non-coherent integration for correaltion value
160
Data processing ends?
No
162
Yes
Determining peak position by means of interpolation
164
Determining pseudo-range
166
Data processing for all Satellites end?
No
168
Yes
End

FIG.4

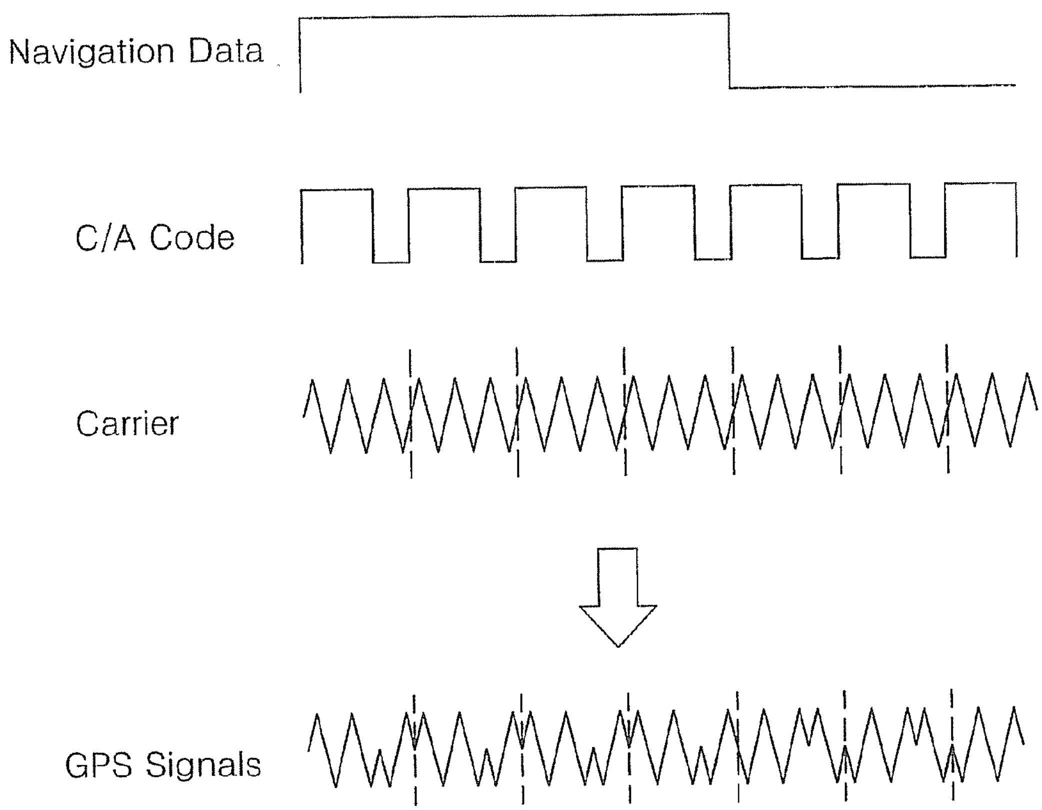


FIG.5

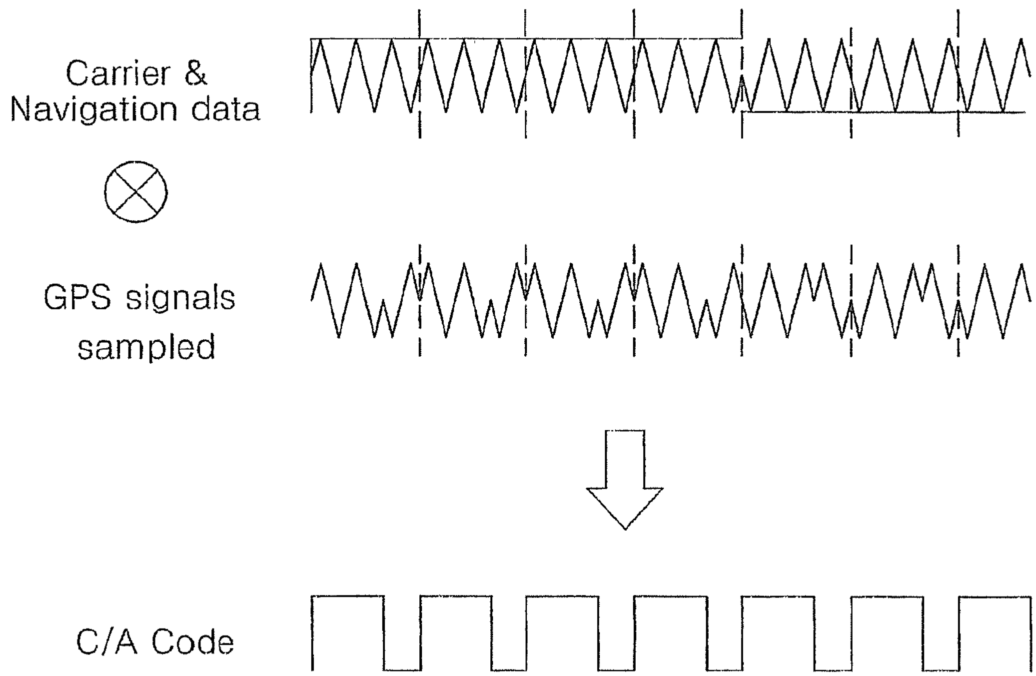


FIG.6

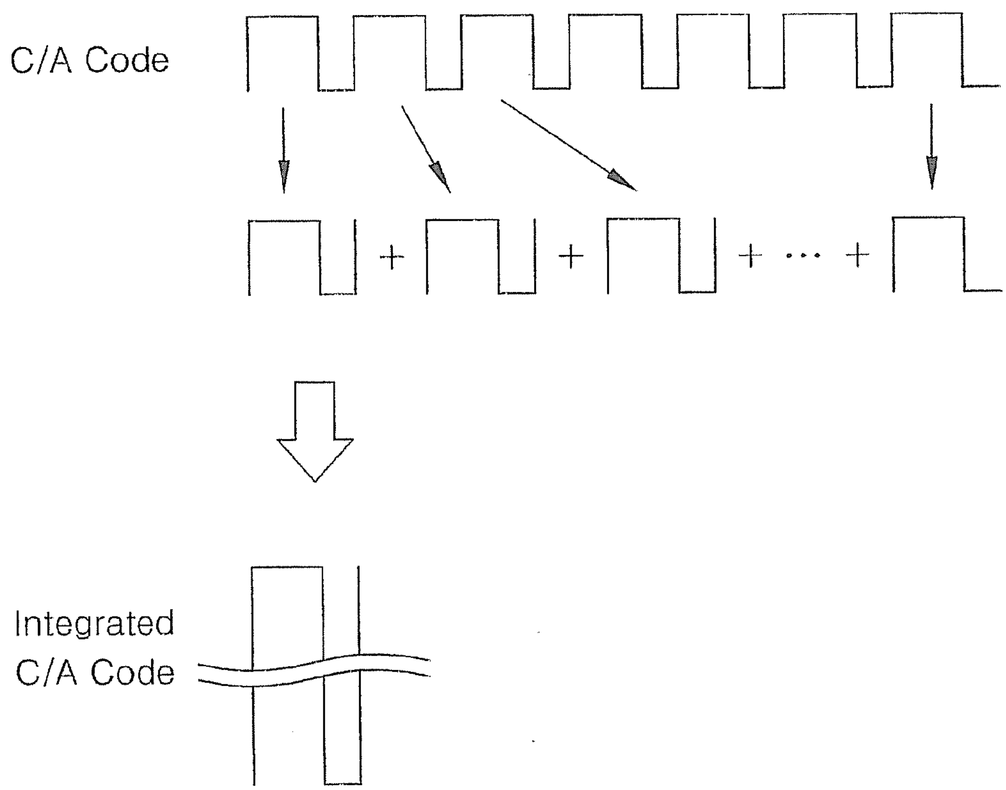


FIG.7

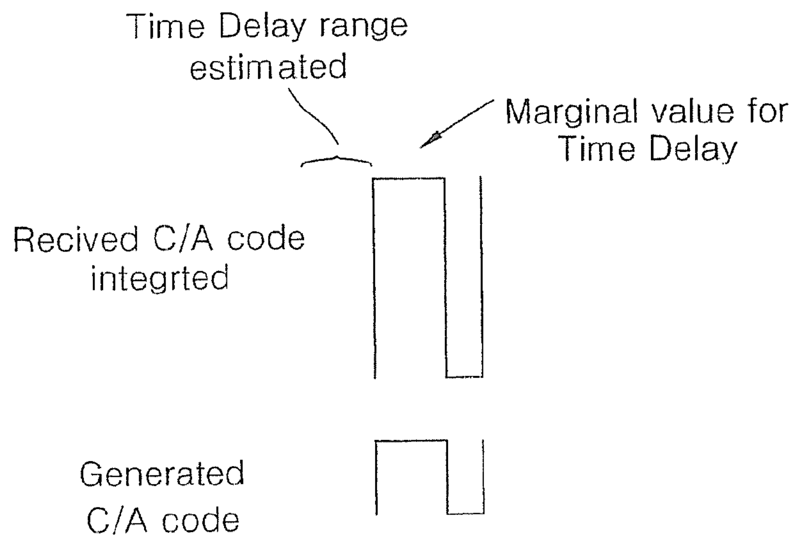

Time Delay range
estimated
Marginal value for
Time Delay
Recived C/A code
integrted
Generated
C/A code

FIG.8

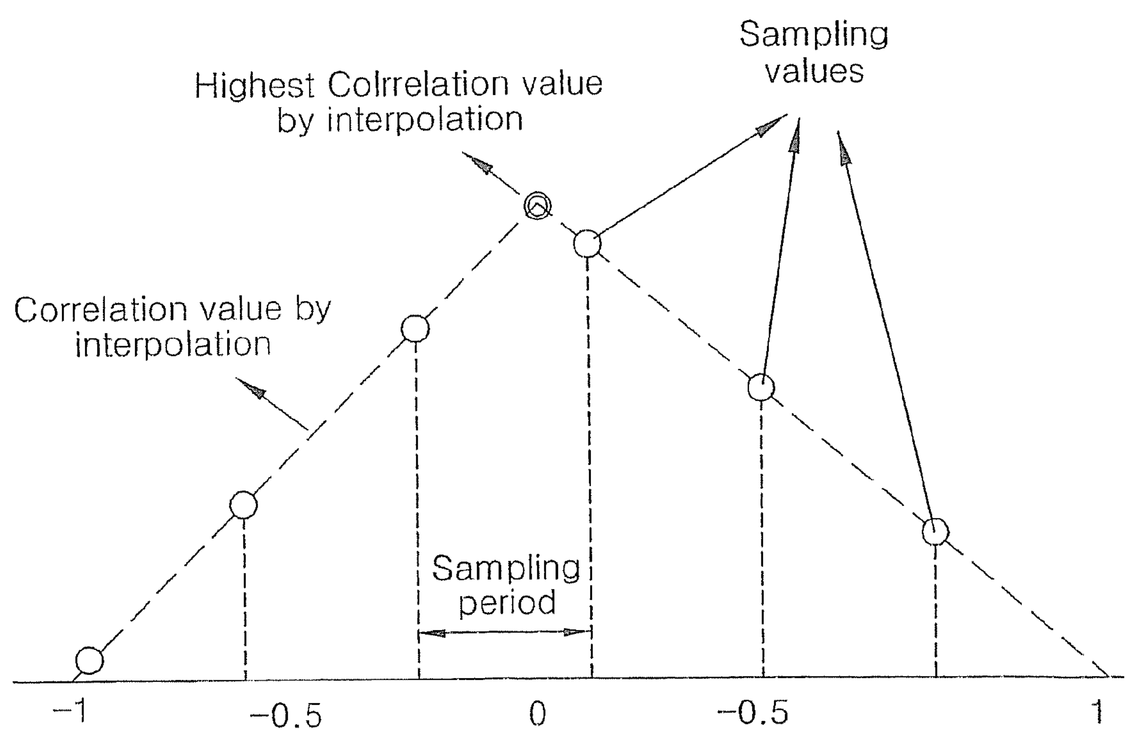

Sampling
values
Highest Colrrelation value
by interpolation
Correlation value by
interpolation
Sampling
period
−1
−0.5
0
−0.5
1

FIG.9

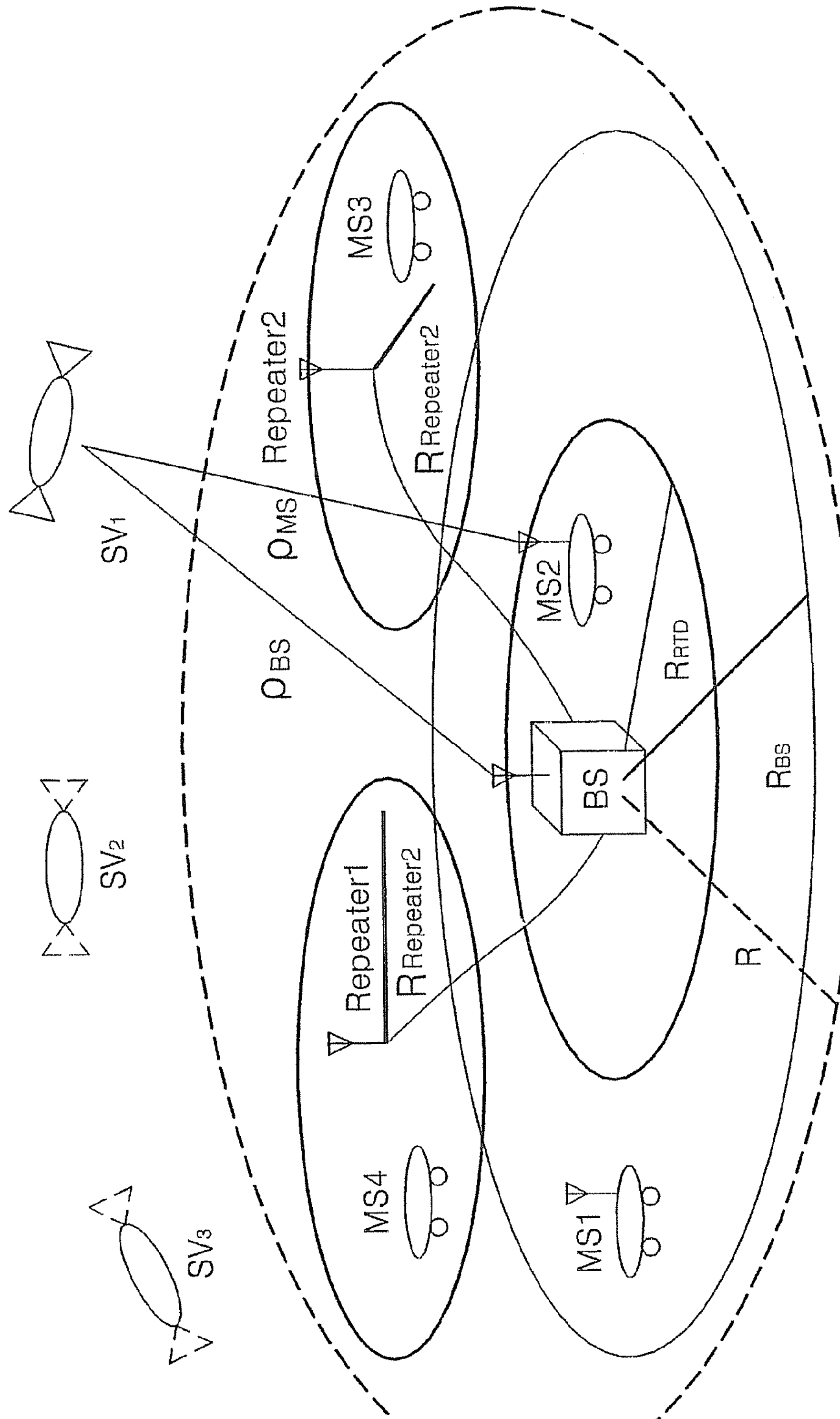

SV_1
SV_2
SV_3
ρ_{BS}
ρ_{MS}
Repeater2
$R_{Repeater2}$
MS3
MS2
R_{RTD}
BS
R_{BS}
R
Repeater1
$R_{Repeater2}$
MS4
MS1

FIG. 10

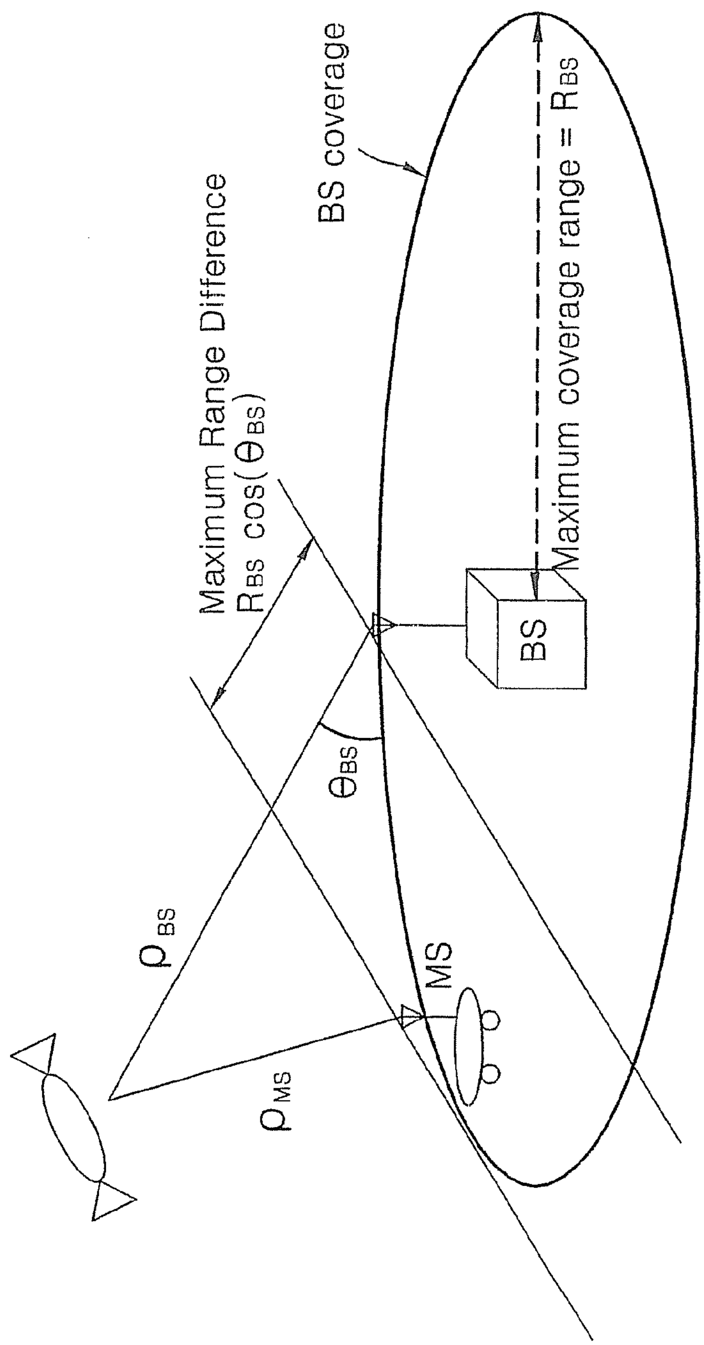

Maximum Range Difference
R_BS cos(θ_BS)
BS coverage
Maximum coverage range = R_BS
BS
θ_BS
ρ_BS
MS
ρ_MS

FIG. 11

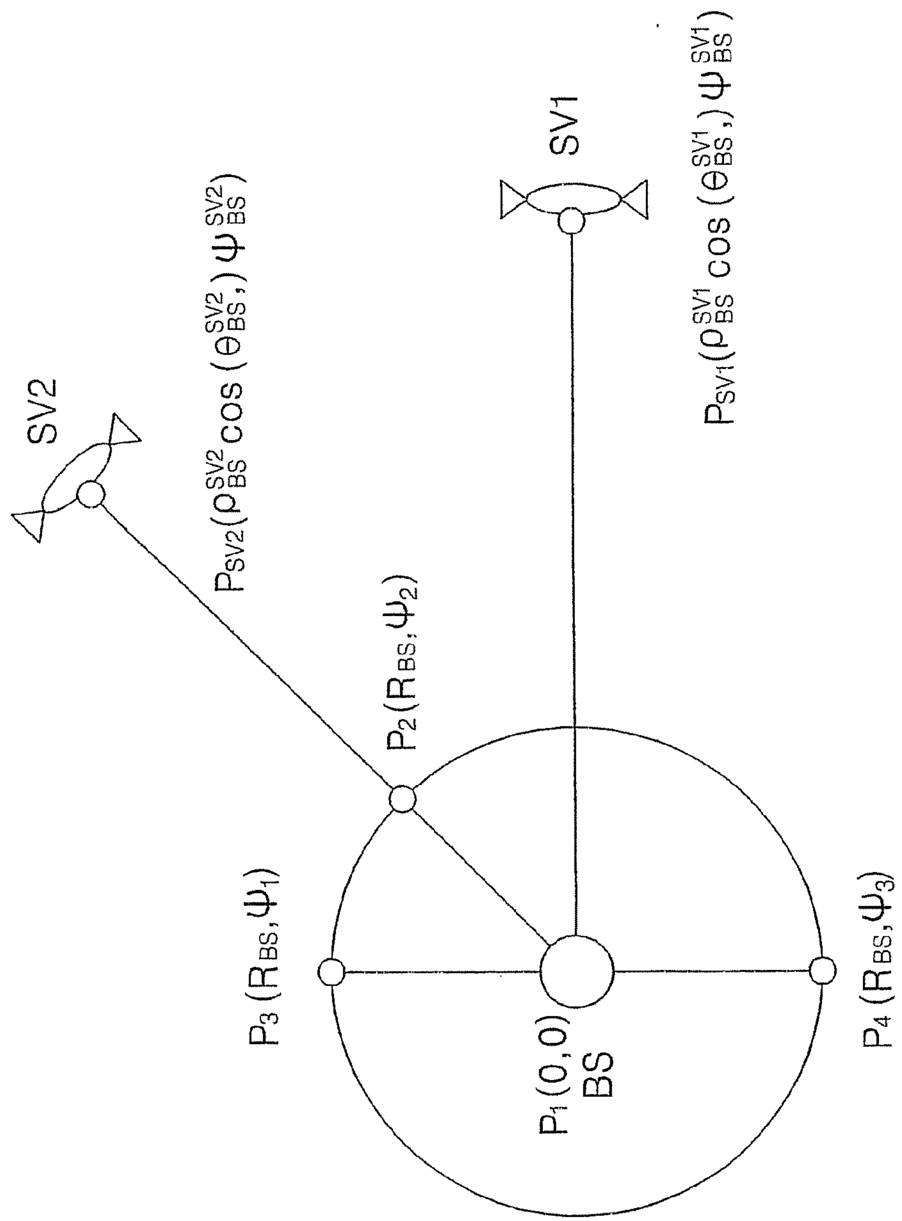

SV2
$P_{SV2}(\rho_{BS}^{SV2} \cos(\theta_{BS}^{SV2},) \psi_{BS}^{SV2})$
SV1
$P_{SV1}(\rho_{BS}^{SV1} \cos(\theta_{BS}^{SV1},) \psi_{BS}^{SV1})$
$P_2(R_{BS}, \psi_2)$
$P_3 (R_{BS}, \psi_1)$
$P_1(0,0)$
BS
$P_4 (R_{BS}, \psi_3)$

FIG. 14

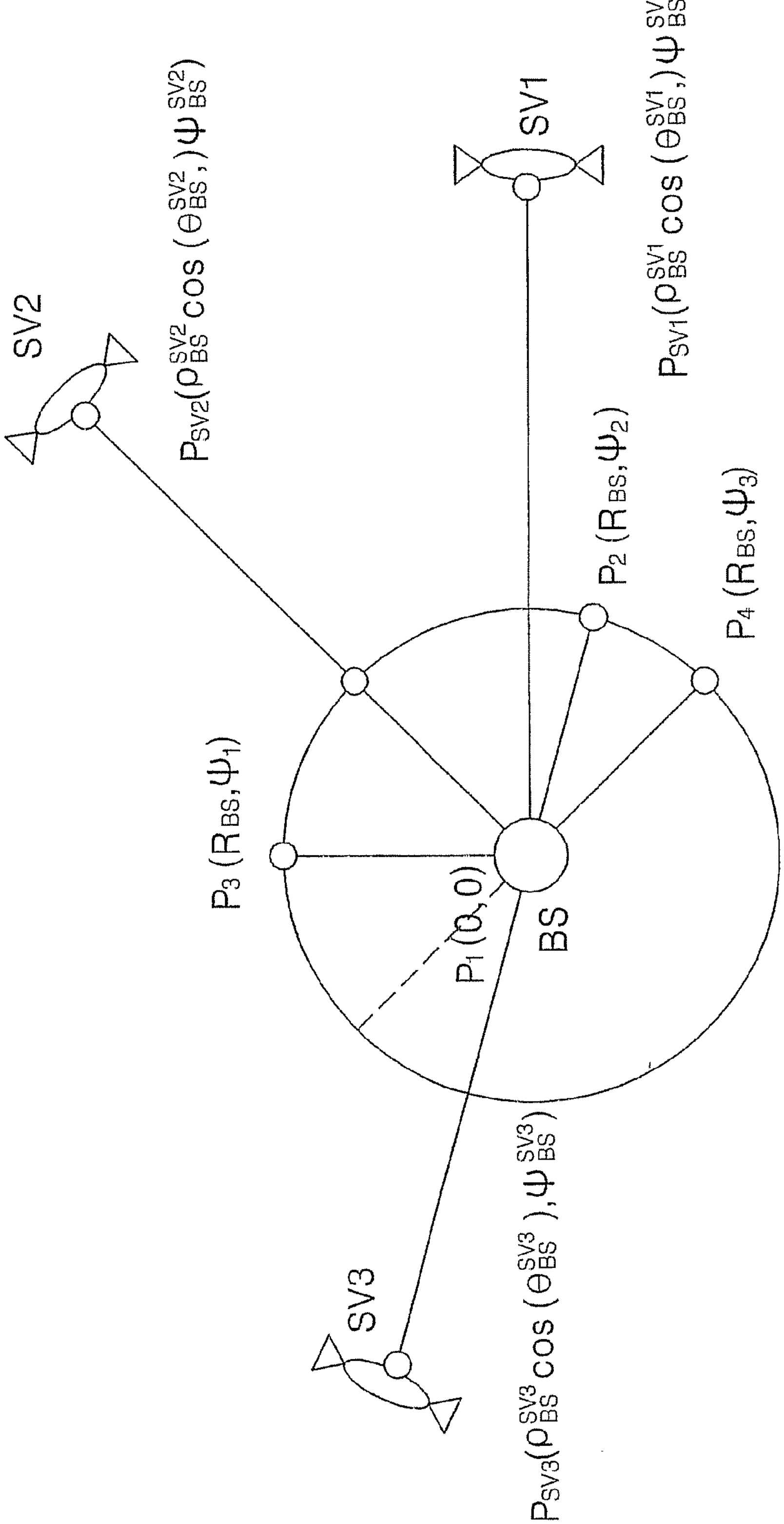

SV1
SV2
SV3
BS
$P_{SV1}(\rho_{BS}^{SV1}\cos(\theta_{BS}^{SV1},)\psi_{BS}^{SV1})$
$P_{SV2}(\rho_{BS}^{SV2}\cos(\theta_{BS}^{SV2},)\psi_{BS}^{SV2})$
$P_{SV3}(\rho_{BS}^{SV3}\cos(\theta_{BS}^{SV3}),\psi_{BS}^{SV3})$
$P_1(0,0)$
$P_2(R_{BS},\Psi_2)$
$P_3(R_{BS},\Psi_1)$
$P_4(R_{BS},\Psi_3)$

FIG. 15

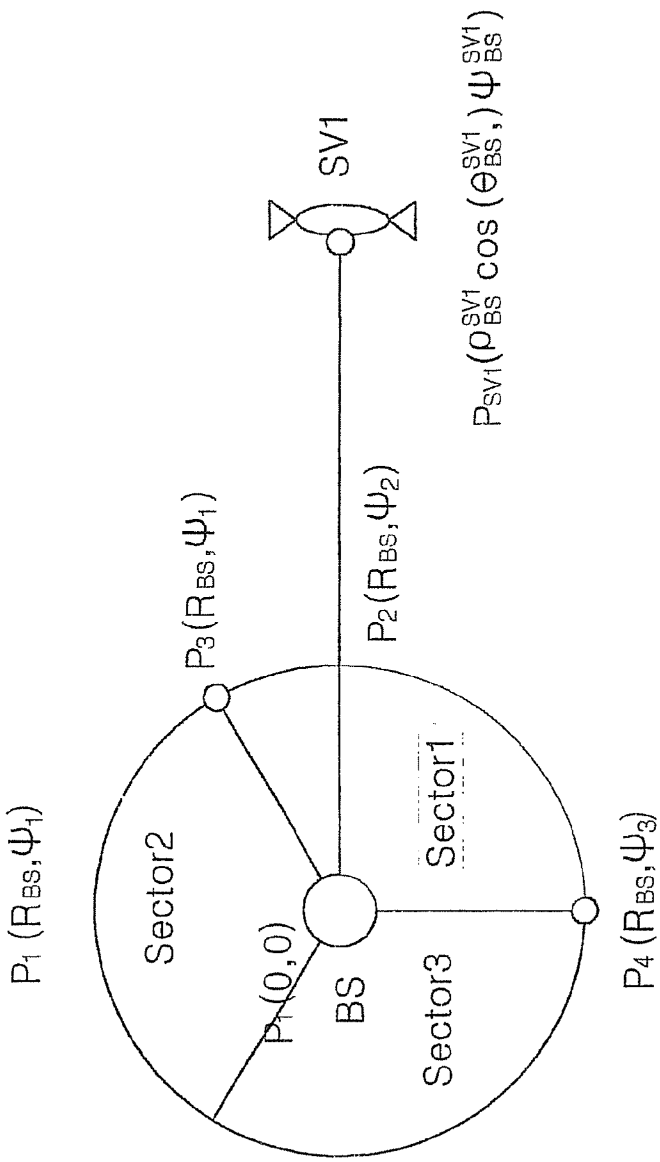

SV1
$P_{SV1}(\rho_{BS}^{SV1}\cos(\theta_{BS}^{SV1},)\psi_{BS}^{SV1})$
$P_2(R_{BS},\psi_2)$
$P_3(R_{BS},\psi_1)$
$P_1\ (R_{BS},\psi_1)$
Sector2
Sector1
Sector3
BS
$P_1(0,0)$
$P_4\ (R_{BS},\psi_3)$

FIG. 16

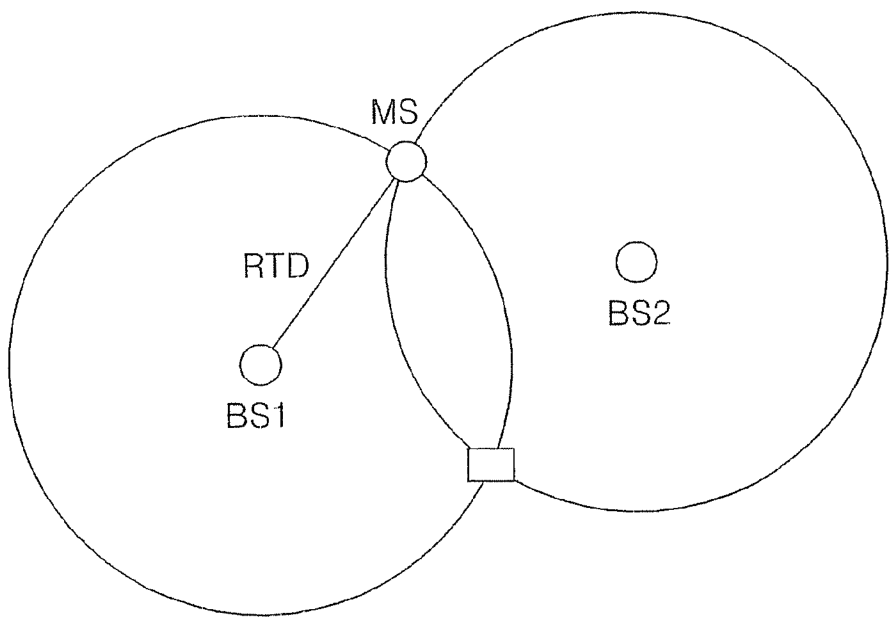


FIG.17

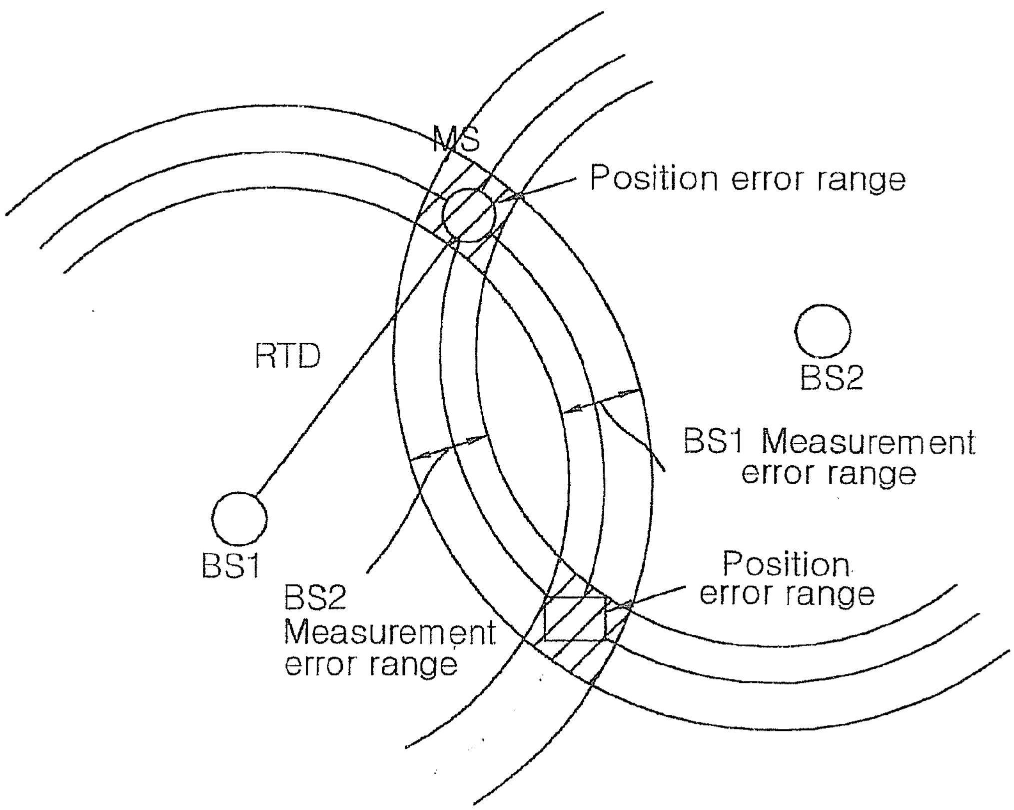

MS
Position error range
RTD
BS2
BS1 Measurement error range
BS1
BS2 Measurement error range
Position error range

FIG.18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR02/01076

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 G01S 1/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC7 G01S 1/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the intertnational search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,663,734 A(Precision Tracking, Inc.) Sep. 2, 1997 See col. 4 ~ 50, fig. 1 ~ 7	1 ~ 13
Y	US 5,841,396 A(SnapTrack, Inc.) Nov 24, 1998 See col 4 ~ 20, fig. 1 ~ 8	1 ~ 13
Y	US 5,884,214 A(SnapTrack, Inc) Mar. 16, 1999 See col. 4 ~ 20, fig. 1 ~ 5	1 ~ 13
Y	US 6,104,340 A(SnapTrack, Inc) Aug 15, 2000 See col 4 ~ 18, fig. 1 ~ 5	1 ~ 13

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevence
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevence; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevence; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 SEPTEMBER 2002 (19.09.2002)	23 SEPTEMBER 2002 (23.09.2002)

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office 920 Dunsan-dong, Seo-gu, Daejeon 302-701, Republic of Korea	KIM, Jae Mun
Facsimile No. 82-42-472-7140	Telephone No. 82-42-481-5673